SCHOOL SCIENCE:

A Book of Methods

To teachers of science, present and future

—who know that teaching is a highly personal invention
—who exercise critical choice in developing
their own teaching
—who will test critically the ways
of the teachers in this book

we submit this accounting of the many
ways of the science teacher.

UNDER THE GENERAL EDITORSHIP OF

Willard B. Spalding
Chairman, Division of Education, Portland State

TEACHING HIGH SCHOOL SCIENCE:

A Book of Methods

HARCOURT, BRACE & WORLD, INC.

Foreword

The way of the science teacher, especially in this age of great successes in science, is hard. Science teachers are expected somehow to be as successful as scientists themselves have been. They are expected to take all the children who come their way and turn, as if by magic, some of them into the scientists of the future and the rest into citizens well prepared to take their place in the world that science has transformed. They are expected to accomplish this in five hours per week or less, over a period ranging from one to six years, with classes composed of perhaps thirty students, no two of whom are alike. One might think that teachers of science would despair at the enormity of the task. Perhaps, in private, many do. But they go into the classroom day after day, prepared to do what they can toward this goal.

This book, and its two companion volumes, can help the science teacher. From them he can learn what other teachers have done, what experimenters have found out about teaching (and its obverse, learning), what may be of use to him in the varied situations in which he finds himself. They should prove invaluable in helping the science teacher, in the words of the authors, "develop his own personal teaching invention."

The authors are all men with wide experience in teaching science and science methods, as is indicated by the abbreviated listing of their affiliations on the title page. All three have also published many articles on various aspects of the field. It is hoped that their experience, and that of the other teachers they describe, will be of use to both present and future teachers of science.

WILLARD B. SPALDING

Caution to the reader

The White Knight, in Lewis Carroll's splendid book which can be considered a satire on "method" in living, packed his luggage for *Nowhere*—a logical thing to do, since he had nowhere to go.

Those who presume to write books on method for teachers seem to think they know where to go; or they think they have some useful things to pack for somewhere; or at least they have a ticket plainly marked with a destination. However, before friends or colleagues buy such a ticket it would be well for them to know the nature of the trip, the quality of the fare, and, of course, the caliber of their companions.

If only we had a formula like $E = mc^2$, with E equal to Educatability, m equal to Mastery of subject matter, and c equal to Creativity! If only we had units like the erg or mho or Mach with which to advance confidently! Those of us fortunate enough to be in teaching like to talk about teaching methods as if they were similar to the laboratory procedures of the technician. But a few days spent in the classroom having our noses bloodied by the hard facts of classroom life, and we realize that we are experts in science education most when we are away from the science classroom.

If expertness in teaching method is indeed less than it should be, if we are dependent more on testimony than on evidence, how then can a book on methods serve the teacher? Each day the teacher goes into the classroom to do his best; each day he strives to do a better job than the day before. And he looks for help. Should he turn to this book and its accompanying volumes (see page x), what is he to expect?

Surely he should expect suggestions which are meant to make his daily teaching more effective. He will find here an attempt to do this in the framework, it is hoped, of sound psychology, sound experience, sound analysis, and sound invention. For teaching is, after all, a personal invention.

Surely he should expect an approach to the solution of problems of science teaching consistent with the ideals and objectives of scientists. Often he will be disappointed because evidence is lacking; research in science education is in its infancy. Yet if we are very careful to identify proven facts, untested hypotheses, and untestable notions, surely we may repair to experience as a guide. When a teacher details his experience to others he may not be

offering evidence, but he may indeed be in the realm of useful testimony relevant to a particular situation, or to a limited range of situations.

And surely the reader of these books should expect help in teaching "scientific methods", for this is required of him not only by specialists but by the community at large. One parent perhaps spoke for the community when he asked that youngsters be taught more than "the mere facts." (As Superintendent Spinning of Rochester asked, "What is so mere about a fact?") The representatives of the community ask that youngsters be taught both the ways of scientists and also the body of facts they have discovered.

The reader will find three volumes to assist him. The present one deals with the tactics and strategy we hope he will find useful in developing his own personal teaching invention. *Teaching High School Science: A Sourcebook for the Biological Sciences* (E. Morholt, P. F. Brandwein, and A. Joseph, 1958) deals with laboratory, field, and demonstration techniques for teaching biology, health, and these areas in general science. *Teaching High School Science: A Sourcebook for the Physical Sciences* (A. Joseph, P. F. Brandwein, and E. Morholt, 1959) does the same for chemistry, physics, earth science, and the physical science areas in general science. Brief tables of contents of these two volumes are given on pages xx and xxi of this one. The three books together are intended to be a teacher's *vade mecum*, his handbook; they are intended to be useful in helping him fashion or refashion his personal teaching invention.

We feel strongly that a book of methods should be not prescriptive but illustrative, and we have organized this book so as to carry out this belief.

First we develop the methods of the scientist and their application to the methods of the science teacher:

Section One The special climate of the science classroom

Chapter 1 Ways of the scientist
Chapter 2 Teaching the ways of the scientist

We then discuss the development of patterns of teaching. This to us does not mean all the methods, techniques, devices, and procedures of the science teacher; it means patterns of teaching concepts and winning participation of students in concept seeking:

Section Two Patterns in teaching science

Chapter 3 Science classes
Chapter 4 Science teachers
Chapter 5 Behavioral objectives
Chapter 6 Winning the concept
Chapter 7 Winning participation
Chapter 8 The science shy
Chapter 9 The science prone

Once we have developed the scientist's pattern of investigation (Section One) and the science teacher's pattern of teaching (Section Two), we proceed to a study of the science teacher's scope and sequence, the nature of the courses he teaches. We are also prepared to discuss the ways in which teachers may develop courses to fit their special needs:

Section Three Inventions in science courses

Chapter 10 Introduction to course building
Chapter 11 Science in the elementary school
Chapter 12 The course in biology
Chapter 13 The course in chemistry
Chapter 14 The course in physics
Chapter 15 The course in general science
Chapter 16 The course in physical science
Chapter 17 The unit in the course
Chapter 18 Building the science course and curriculum, continued

Then one must know whether objectives have been attained, whether children have been helped to grow, whether changes in behavior have occurred; we continue with:

Section Four Determining the success of science teaching

Chapter 19 Appraising the student: a general approach to evaluation
Chapter 20 Appraising the student: an approach to test building and interpretation
Chapter 21 Appraising the teacher's role: supply and demand in science

We know that one book cannot be all things to all teachers. We include here only a brief section, of which the other two books in the series are really the expansion, on procedures:

Section Five Tools for the science teacher

The demonstration; the chalk-board; the film, with directory of distributors; the film-strip, with directory of distributors; the library lesson; the laboratory lesson, with a note on workbooks; the field trip; the textbook; the assignment; the report; the project; science clubs and science fairs; student laboratory squads; the bulletin board and the exhibit case; science facilities, with directory of suppliers; the professional library; the expert, with a note on becoming one; the resource file: where to go for further help

And we conclude with a section containing verbatim reports on just what three different communities have done and are planning to do to accomplish our goal of improving science teaching:

Section Six Blueprints for community action

The Detroit science education story; the Indianapolis science education story; the Oklahoma science education story

We should like to take this opportunity to thank a few of those who have provided encouragement and assistance: Arthur Greenstone for collaboration in the preparation of Chapters 13 and 14, and Herbert Drapkin and Philip Johnson for reading critically galley proof of the whole book.

These three books are really one attempt to provide a foundation for the development of individual patterns in science teaching. Teaching remains a personal invention, designed to help young people understand the world in which they live.

PAUL F. BRANDWEIN

FLETCHER G. WATSON

PAUL E. BLACKWOOD

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TEACHING HIGH SCHOOL SCIENCE: *A Sourcebook for the Physical Sciences*

by Alexander Joseph, Paul F. Brandwein, and Evelyn Morholt

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Section One | THE SPECIAL CLIMATE OF THE SCIENCE CLASSROOM

Sooner or later the discussion at teachers' meetings, conferences, and conventions usually resolves into one solution of the problem of improving science teaching: getting better teachers. Then, often, two exaggerated images of teachers appear. One is of the modern "good" or "inspiring" teacher, a vigorous, dynamic, intelligent, informed, friendly, warm person who likes children and is devoted to society. In his or her classroom the atmosphere is conducive to learning; the climate is cheerful, social, clean, permissive; relationships between student and teacher are creative and democratic. The content of the course is based on the needs and interests of the individual; the aim of education is to have each child grow to his utmost, develop to his fullest potential. Children learn science by doing; the lesson is an experience in search of meaning.

The other stereotype is of the "uninspiring" teacher, who feels that children don't want to learn but must be made to learn, that they are undisciplined, disrespectful, and unwilling to work: "It is good for children to work hard to learn self-discipline; this will help them become better people. Every youngster must know certain things in order to succeed in life. The child will grow best when he is forced to do his work; and this work consists of college-preparatory courses. If the youngster is not successful in these courses, he deserves to fail, for he is definitely not prepared for life."

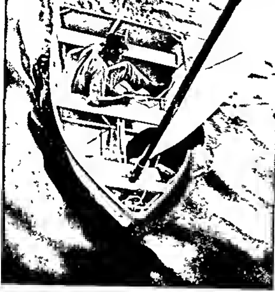
Of course, these are caricatures, not real people. Nevertheless, a teacher does establish a climate in his classroom, as well as an individual pattern of teaching. And in science, particularly, the climate of the classroom is determined not only by the personality of the teacher but also by the character of the subject; the method of the scientist and the method of the science teacher go hand in hand.

The stuff of science, the experiences in which the scientist finds meaning, are everywhere about us—wherever a life is born, an insect or a rocket flies, a book is opened—there science is being taught and learned: in the following pages, and in our classrooms.

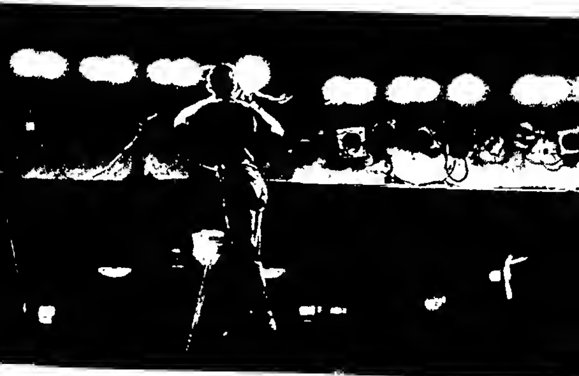
WE TAKE FOR AN INTRODUCTION
THESE WORDS OF ALBERT EINSTEIN:

*"The most beautiful
and most profound emotion
we can experience
is the sensation
of the mystical.*

It is the dower
of all true science.

He to whom this emotion
is a stranger,
who can no longer wonder
and stand
rapt in awe,
is as good as dead."



"It is the supreme art of the teacher to awaken joy in creative expression and knowledge."

CHAPTER 1

The special climate of the science classroom:

Ways of the scientist

A note at the beginning: We have at hand 42 syllabuses, from 37 states, for general science, biology, physics, chemistry, earth science, and physical science courses. They have one thing in common; all propose to teach *the scientific method.* Forty-one of them seem to deal with the "empirical approach," the slowest, least effective way of "problem solving."

Actually the word "science" stands for such a complex variety of information, abilities, and operations that none of the many published definitions seems wholly adequate. We hesitate to add one more effort to compress the grandeur of science and scientific work into a brief pattern of words. However, perhaps we can clarify what science *isn't,* and suggest explicitly what it *involves.* Many eminent scientists and philosophers have written about the nature of science; those readers who wish to go beyond our discussion may find the books listed at the end of the chapter helpful.

One peculiarity of ours will certainly not escape you: we tend to think of science more as a *verb* than as a *noun;* we tend to think of the way a scientist *works* rather than what science *is.* We think that science is more concerned with the process by which a body of reliable knowledge is obtained than with the resulting body of knowledge itself. Consequently when we talk of *science,* we shall really be talking about *ways in which scientists seek concepts.*

The so-called "scientific method"

To predict what an individual scientist will do is hazardous, for as individuals they do a variety of activities in different ways. However, there are some common attributes of "scientific" behavior, and these are what we are

Quotations by Albert Einstein, from *Out of My Later Years*, New York: Philosophical Library, 1950, and motto on the Astronomy Building of Pasadena Junior College, California

PHOTOGRAPHS Page 2 Ken Heyman Page 3, Lucien Aigner from Monkmeyer Page 4 top Arline Strong bottom Black Star Page 5, top left: Carola Gregor from Monkmeyer bottom left, Bob Jones right: Robert J Smith from Black Star Page 6 Eugene Tulchin Page 7, top Morris Rosenfeld bottom Alfred Wertheimer Page 8, left and top right, Nancy Hays from Monkmeyer bottom right Phil Palmer from Monkmeyer Page 9 Paul George Schutzer

Scientific method is something talked about by people standing on the outside and wondering how the scientist manages to do it. These people have been able to uncover various generalities applicable to at least most of what the scientist does, but it seems to me that these generalities are not very profound, and could have been anticipated by anyone who knew enough about scientists to know what is their primary objective. I think that the objectives of all scientists have this in common—that they are all trying to get the correct answer to the particular problem in hand. This may be expressed in more pretentious language as the pursuit of truth. Now if the answer to the problem is correct, there must be some way of knowing and proving that it is correct; the very meaning of truth implies the possibility of checking or verification. Hence the necessity for checking his results always inheres in what the scientist does. Furthermore, this checking must be exhaustive, for the truth of a general proposition may be disproved by a single exceptional case. A long experience has shown the scientist that various things are inimical to getting the correct answer. He has found that it is not sufficient to trust the word of his neighbor, but that if he wants to be sure, he must be able to check a result for himself. Hence the scientist is the enemy of all authoritarianism. Furthermore, he finds that he often makes mistakes himself and he must learn how to guard against them. He cannot permit himself any preconception as to what sort of results he will get, nor must he allow himself to be influenced by wishful thinking or any personal bias. All these things together give that "objectivity" to science which is often thought to be the essence of the scientific method.

But to the working scientist himself all this appears obvious and trite. *What appears to him as the essence of the situation is that he is not consciously following any prescribed course of action, but feels complete freedom to utilize any method or device whatever, which in the particular situation before him seems likely to yield the correct answer. In his attack on his specific problem he suffers no inhibitions or precedent or authority, but he is completely free to adopt any course that his ingenuity is capable of suggesting to him. No one standing on the outside can predict what the individual scientist will do or what method he will follow. In short, science is what scientists do, and there are as many scientific methods as there are individual scientists.*

Science progresses as the explanations (or concepts)[1] it produces for previously unexplained things or events both fit the facts on which they were based and lead to new predictions which can be tested. The results of these tests may or may not agree with these predictions. If they do agree, our confidence in the explanation is bolstered, for we then have added one more set of phenomena which we can predict. If, however, after repeated experimental work our expectations and observations do not agree, or do not agree as well as we would like, then our explanation must be re-examined to remove, if possible, the new discrepancy. And so we have a continuous round of discrepancy, explanation, prediction, test, new facts, new explanation.

This self-correcting process is basic to all scientific work. But individual scientists, despite their best intentions, are biased, misinterpret data, and formulate erroneous explanations. Then how is it that we attain any increase in predictive ability? Independence, in science at least, has its price; the independence of each individual, as Bridgman noted, imposes upon him a continu-

[1] In this chapter we shall use the term "concepts" in its dictionary sense, as equivalent to "idea" or "principle" or "generalization." For its more technical meaning see Chapter 6.

searching for. Unfortunately a great myth has developed that the scientist has some special, even regular, way of proceeding; he has, too many people believe, a "scientific method," which is the key to his success. Often this scientific method is reduced to five steps:

1. Define a problem.
2. Gather relevant data.
3. Form hypotheses.
4. Test the hypotheses.
5. Reach a conclusion.

No one will deny that scientists do all these things, but knowing that they "define problems" is no more help to us in doing likewise, or even in understanding what they are doing, than knowing that artists "paint pictures." What this scheme does not tell us is exactly what we need to know: What operations are represented by the verbs? Let us describe a "method" of mountain climbing in the same way:

1. Select an unclimbed mountain.
2. Organize a party.
3. Plan the equipment.
4. Go to and climb the mountain.
5. Plant a flag on the top.

Mountain climbers do these things, but does this analysis help you to "select," "organize," "plan," or "climb"? The analysis may be correct but it is sterile, it does not aid us in performing or even understanding these operations.

Percy Bridgman, Nobel Laureate in Physics, cuts a broad swath through the definition of the methods of science by a general statement which appeals to many other scientists: "The scientific method, as far as it is a method, is nothing more than doing one's damnedest with one's mind, no holds barred." [1] He goes further, in an article addressed to teachers, to say (the italics in the final paragraph are ours). [2]

> It seems to me that there is a good deal of ballyhoo about scientific method. I venture to think that the people who talk most about it are the people who do least about it. Scientific method is what working scientists do, not what other people or even they themselves may ask about it. No working scientist, when he plans an experiment in his laboratory, asks himself whether he is being properly scientific, nor is he interested in whatever method he may be using as *method*. When the scientist ventures to criticize the work of his fellow scientist, as is not uncommon, he does not base his criticism on such glittering generalities as failure to follow the "scientific method," but his criticism is specific, based on some feature characteristic of the particular situation. The working scientist is always too much concerned with getting down to brass tacks to be willing to spend his time on generalities.

[1] P. W. Bridgman, "Prospect for Intelligence," *Yale Review*, *34*, 450, 1945, reprinted in *Reflections of a Physicist*, Philosophical Library, N. Y., 1950, p. 342.
[2] P. W. Bridgman, on "Scientific Method," *The Teaching Scientist*, Dec. 1949, p. 23.

door. This follows the route of the systematic "try it and see" or "trial and error" approach. The "method of solution" might even be placed on the blackboard thus:

Problem: To open the door
Apparatus: Keys
Method (observations): Try in sequence each key
Operation: Systematic trials
Conclusion: Key No. 1007 opens the door

If the reader objects and says that this is simply common sense, he is correct. The "try it and see" (empirical) approach is a common-sense approach, and it is used in many fields of endeavor besides science. Much of the laboratory work useful in defining the characteristics of new phenomena is precisely this: a systematic "try it and see," or *empirical* approach. Note that empiricism when effective *is systematic;* that is, it is guided by ideas and concepts. Without such guiding ideas, activity in concept attainment is futile.

Empiricism in the laboratory

Let us look at a laboratory investigation which exhibited a high degree of empiricism: the making of complex iron alloys. Small changes in the percentages of many elements (carbon, silicon, phosphorus, nickel, or sulfur) were known to alter the properties of the final alloy. Yet desired properties could not be obtained by prediction; for no reliable generalized explanation, no *concept* about the interactions of several metallic components, had been proposed. The systematic making and testing of many individual samples was the only way to discover how they would behave. Later, if desired, any of the sample alloys could be duplicated, but the properties of a new alloy could not be predicted, nor could an alloy of given properties be designed.

This is an example of almost pure empiricism; empiricism allows us to choose only among the things we have already done. Thus empiricism, though indispensable, when unaccompanied by some effort to attain *prediction* is a slow and fairly unsatisfactory way to get results.

Empiricism in the classroom

Crude empiricism often appears in the classroom. A question is asked, by the teacher or a student, which leads possibly to one of the following statements below:

Let's do an experiment.
We're scientists. Let's *try it and see.*[1]

Suppose the question is "Does air have pressure?" (It is hard to believe that students would worry very much about this, but the lesson remains a

[1] Students in the high school science classroom are not, of course, "scientists," any more than one who writes a composition is a "writer," or one who draws in the art class is an "artist."

ous attitude of constructive skepticism toward his own work and that of others. Diversity of explanation of known data is not only unavoidable but essential; indeed, diverse explanations are assiduously sought. A fundamental aspect of science, as it has evolved over the centuries, is that the alternate answers which arise in this way, incomplete or erroneous as they probably are, are so formulated that each is susceptible to additional testing, and thus is productive of *further concept attainment.*[4] Concept attainment is a goal of the scientist.

Consider, for example, the explanation of the origin of continental glaciers, the great ice sheets which a few thousand years ago covered a considerable part of the United States. Evidence convinces us that such ice sheets did exist. But what was the mechanism of their formation? Can we predict the conditions under which they would reappear? William L. Stokes stated that to his knowledge twenty-nine different explanations were in the literature, and he went on to say that "Most of these had little chance of survival from the first, but others enjoyed some degree of success until they were rendered untenable by subsequent accumulated information." Not content, he went on to propose a thirtieth explanation.[5]

Such a multiplicity of effort may seem wasteful, but it surely is not; only by having a variety of different trial explanations, based on different selections of data and physical mechanisms, can we obtain the clues we need in order to make further useful observations. These observations can be expected to weed out many of the trial explanations.

Empiricism—one way of the scientist

Many discussions of science, or of "scientific method," point to empiricism as the essence of science, as do the syllabuses mentioned at the beginning of this chapter. Let us take a look, for a moment, at this empiricism and see what it is.

Empiricism and common sense

Conant[6] has illustrated the sense of empiricism, the "cut and try" approach, by a commonplace example. Take out a set of keys and ask someone to unlock a given door. Clearly the approach to the solution of this problem is empirical, lacking any clues, any basis of selection, any hypothesis to guide him, the "experimenter" will *try* the keys until he finds one which opens the

[4] We use the term concept attainment as it is used by Jerome S. Bruner, Jacqueline J Goodnow, and George S. Austin, in *A Study of Thinking*, Wiley, N. Y., 1956 Essentially we are attempting to distinguish between the problem doing in which students in our established courses engage (which results in confirming concepts already discovered; these cannot be escaped if they follow instructions or the teacher's carefully directed *questioning*) and the problem solving of scientists which is actually directed at concept attainment. These concepts are *new* relationships. In Chapter 6 we discuss, within the limits of this work, the nature of concept seeking

[5] "Another Look at the Ice Age," *Science, 122,* 815, 1955.

[6] James B. Conant, *Science and Common Sense,* Yale U Press, New Haven, 1951.

Redi's investigation [10]

It being thus, as I have said, the dictum of ancients and moderns, and the popular belief that the putrescence of a dead body, or the filth of any sort of decayed matter engenders worms; and being desirous of tracing the truth in the case, I made the following experiment:

At the beginning of June I ordered to be killed three snakes, the kind called eels of Aesculapius. As soon as they were dead, I placed them in an open box to decay. Not long afterwards I saw that they were covered with worms of a conical shape and apparently without legs. These worms were intent on devouring the meat, increasing meanwhile in size, and from day to day I observed that they likewise increased in number; but although of the same shape, they differed in size, having been born on different days.

But all, little and big, after having consumed the meat, leaving only the bones intact, escaped from a small aperture in the closed box, and I was unable to discover their hiding place. Being curious therefore, to know their fate, I again prepared three of the same snakes, which in three days were covered with small worms. These increased daily in number and size remaining alike in form, though not in color. Of these, the largest were white outside, and the smallest ones, pink. When the meat was all consumed, the worms eagerly sought an exit, but I had closed every aperture. On the nineteenth day of the same month some of the worms ceased all movements, as if they were asleep, and appeared to shrink and gradually to assume a shape like an egg. On the twentieth day all the worms had assumed the egg shape, and had taken on a golden white color, turning to red, which some darkened, becoming almost black. At this point the red, as well as the black ones, changed from soft to hard, resembling somewhat those chrysalids formed by caterpillars, silkworms, and similar insects. My curiosity being thus aroused, I noticed that there was some difference in shape between the red and the black eggs [pupae], though it was clear that all were formed alike of many rings joined together; nevertheless, these rings were more sharply outlined, and more apparent in the black than in the red, which last were almost smooth and without a slight depression at one end, like that in a lemon picked from its stalk, which further distinguished the black egg like balls. I placed these balls separately in glass vessels, well covered with paper, and at the end of eight days, every shell of the red balls was broken, and from each came forth a fly of gray color, torpid and dull, misshapen as if half finished, with closed wings; but after a few minutes they commenced to unfold and to expand in exact proportion to the tiny body which also in the meantime had acquired symmetry in all its parts. Then the whole creature, as if made anew, having lost its gray color, took on a most brilliant and vivid green; and the whole body had expanded and grown so that it seemed incredible that it could ever have been contained in the small shell. Though the red eggs [pupae] brought forth green flies at the end of eight days, the black ones labored fourteen days to produce certain large black flies striped with white, having a hairy abdomen, of the kind that we see daily buzzing about the butcher's stalls.

U. Press, Cambridge, 1950 1953

I. B. Cohen, *Science, Servant of Man*, Little, Brown, Boston, 1949.

W. I. B. Beveridge, *The Art of Scientific Investigation*, W. W. Norton, N. Y., 1950.

[10] Francesco Redi (1626-1697). From *Esperienze intorno alla generazione degl'insetti, fatte da Francesco Redi e da lui scritte in una lettera all'illustrissimo Signor Carlo Dati*, Florence, 1688, translated by M. Bigelow as *Experiments on the Generation of Insects, by Francesco Redi*, Open Court Publishing Co., Chicago, 1909.

standard one.) The teacher writes the problem on the board: "Does air have pressure?" Then an outline on the board follows, something like this: [8]

Problem Does air have pressure?

Apparatus needed. A can, burner, stopper, tripod, and water.

Observations. (Written by students in their notebooks. This is a description of what they "tried" and "saw") "We heated the water in the can until steam appeared Then we put a stopper in the can As the can cooled, its walls began to collapse"

Argument: Since the steam displaced the air, a partial vacuum was produced inside The collapse of the can must have been due to a force acting on the outside *This force is the pressure of air.* (No other explanation seems adequate)

Conclusion Air exerts pressure.

There is nothing wrong with using simple empiricism; we all do it daily and the scientist does it too. However, in the example just cited a great many things are wrong, both scientifically and pedagogically. No real problem existed for the students, for there was no discordant observation, no trial explanation, not even an "educated guess." There was no testing of a hypothesis by testing its consequences There was no design or even selection of equipment with which to gather the needed information. And, of course, there could be no reasoning to fit the new information to an initial explanation.

This demonstration, done to the death, is really quite sophisticated. The student cannot see what is happening in the can, and he must recall considerable information if he is to "believe" the explanation desired His tacit agreement to many concepts (principles) is assumed: water as vapor occupies a much larger space than as liquid; water vapor will displace air, upon cooling water vapor condenses with a lowering of the gas pressure (inside the stoppered can) Then he may be able to visualize the difference in pressure inside and outside the can which resulted in its collapse. Finally attention is focused on the question. What is the origin of the external pressure? In short, more than the empirical approach is necessary to understand what is really happening--insight, for instance, as well as prior experience and reading.

Ways of the scientist: planned investigation

So far we have attempted to describe empiricism, the "try it and see" approach. We have seen that it is indeed a part of the scientific approach; we cannot picture a scientist unwilling to go into the laboratory and "try it." But "it" is always a specific operation or reaction seemingly worth the effort to "try." In other words, more than empiricism is involved in science.

Let us examine a classic investigation and analyze the operations involved, both physical and intellectual, from beginning to end.[9]

[8] Taken from the board work of a teacher of science in "Hearsay" High School.

[9] The accompanying volume by E. Morholt, P. Brandwein, and A Joseph, *Teaching High School Science A Sourcebook for the Biological Sciences*, details a number of such readings. A good number of such cases are also given by:

J B Conant, Duane Roller, Leonard Nash *et al.*, *The Harvard Case Studies*, Harvard

Redi's "pattern of investigation"

1. [There is a] dictum that the putrescence of a dead body, or the filth of any sort of decayed matter, engenders worms; and being desirous of tracing the truth . . . made the . . . experiment. (lines 1-4)

1. A widely accepted explanation has never been tested. Suspicion is aroused. A test is designed.

2. Having considered these things I began to believe that all worms found in meat were derived directly from the droppings of flies, and not from the putrefaction of the meat. (lines 46-48)

2. The preliminary test has yielded observations which do not agree with the accepted explanation. These observations suggest an informed guess—a *working hypothesis.* A new concept has been formed; it deserves testing.

3. Belief would be useless without the confirmation of experiment, hence in the middle of July, I put . . . (lines 50-54)

3. An experiment is designed to test this hypothesis under devised conditions. A control is used for comparison.

4. It was not long before the meat and fish in the [open] vessels became wormy . . . [but] in the closed flasks I did not see a worm. (lines 54-57)

4. The experimental design of the operation is found useful. Differences between the experiments and control cases support the tentative hypothesis; they do not support the accepted belief.

5. Not content with these experiments, I tried many others at different seasons, using different vessels. (lines 62-63)

5. Further observations are made in order to generalize the observation.

6. In order to remove all doubt . . . I prepared a new experiment . . . (lines 75 ff.)

6. A further modification in design broadens the evidence to clarify the effects of the air.

7. I never saw any worms in the meat . . . (lines 80 ff.)

7. The working hypothesis has been checked, minor variables have been eliminated, and the hypothesis has been supported by all the available evidence.

We may generalize this pattern taking into account the work of many scientists:

1. There seems to be a difference between what is observed and what is expected; or a vague explanation has been generally accepted without testing.

> Having considered these things, I began to believe that all worms found in meat were derived directly from the droppings of flies, and not from the putrefaction of the meat, and I was still more confirmed in this belief by *having observed that, before the meat grew wormy*, flies had hovered over it, of the same kind as those that later bred in it. Belief would be in vain without the confirmation of experiment, hence in the middle of July, I put a snake, some fish, some eels of the Arno, and a slice of milk fed veal in four large, wide mouth flasks, having well closed and sealed them. I then filled the same number of flasks in the same way, only leaving these open. It was not long before the meat and the fish, in the second vessels, became wormy and flies were seen entering and leaving at will, in the closed flasks I did not *see a worm, though many days had passed since* the dead flesh had been put in them. Outside on the paper cover there was now and then a deposit, or a *maggot that* eagerly sought *some crevice* by *which to* enter and obtain nourishment. Meanwhile the different things placed in the flasks had become putrid,
>
> Not content with these experiments, I tried many others at different seasons, using different vessels In order to leave nothing undone, I even had pieces of meat put under ground, but though remaining buried for weeks, they never bred worms, as was always the case when flies had been allowed *to* light on the meat One day a large number of worms, which had bred in some buffalo meat, were killed by my order, having placed part in a closed dish, and part in an open one, nothing appeared in the first dish, but in the second worms had hatched, which changing as usual into egg-shaped balls [pupae], finally became flies of the common kind In the same experiment tried with dead flies, I never saw anything breed in the closed vessel
>
> Leaving this long digression and returning to my argument, it is necessary to tell you that although I thought I had proved that the flesh of dead animals could not engender worms unless the semina of live ones were deposited therein, still, in order to remove all doubt, as the trial had been made with closed vessels into which the air could not penetrate or circulate, I wished to attempt a new experiment by putting meat and fish in a large vase closed only with a fine Naples veil that allowed the air to enter. For further protection against flies, I placed the vessel in a frame covered with the same net. I never saw any worms in the meat, though many were to be seen moving about on the net covered frame. These, attracted by the odor of the meat, succeeded at last in penetrating the fine meshes and would have entered the vase had I not speedily removed them It was interesting, in the meanwhile, to notice the number of flies buzzing about which, every now and then, would light on the outside net and deposit worms there. I noted that some left six or seven at a time there and others dropped them in the air before reaching the net. Perhaps these were of the same breed mentioned by Scaliger, in whose hand, by a lucky accident, a large fly deposited some small worms, whence he drew the conclusion that all flies bring forth live worms directly and not eggs. But what I have already said on the subject proves how much this learned man was in error It is true that some kinds of flies bring forth live worms and some others eggs, as I have proved by experiment

Redi "tried it and saw." However, this is not all he did; let us analyze his approach. Our two column form separates the "*evidence*" *(what Redi said)* from our generalized comment.

Ways of the scientist: key operations

We have seen from a study of Redi's work that there is sometimes a discernible pattern to a scientist's investigation, his way of getting at concepts. Is Redi's investigation a template of what all scientists do? If we examine the key operations of different scientists perhaps we can find some things common to them all.

Before the problem

Any study begins with a familiarity with the phenomenon, with "what sort of thing it is." Otherwise one doesn't recognize a discrepancy, or a dissatisfaction with things as they are. Concept seeking begins with the realization that the concept in hand is not adequate to fit the observed events.

This may be evidenced by a vague feeling of dissatisfaction with things as they are, or it may be as concrete as "I wonder what is the pressure of the air on the top of the Washington Monument." The problem—something to be explored, to seek the answer to—must be interesting or tantalizing or "fun." (For students it should have meaning; it is expected that they will work hard. But the problem *should not be so complex* that there is little or no hope that the pupils, with the background and experience they have had, can organize a usable explanation, that is, attain the concept.)

Casual observation and description is followed by recognition of those aspects which begin to seem important. Such descriptions and classification are important in seeking any explanation, but they are part of the *beginning*, not the end, of the study. Carefully gathered data are the stuff of which explanations are built, but they may have, as Henri Poincaré remarked, the same relation to a scientific concept as a pile of stones has to a house.

Note that we have said "carefully gathered data"; the data must be sought carefully and must be relevant to the problem. Simpson, Pittendrigh, and Tiffany [11] put it this way:

> Fact gathering in the hands of a scientist is a cultivated art; there is an infinity of facts in the world, and at any given time only a few of them are of vital importance to him.
>
> Are you being a scientist when you count the sand grains on Coney Island beach? No. It is true you are gathering facts . . . but you are probably crazy. Scientists gather facts that are *relevant* . . . to some theory to be tested or extended.

Hence the problem must be clearly stated, and, what is as important, the kind of explanation or solution suspected must be sketched *in advance* of experimental work. In fact, scientists "see" the solution almost at the same time that they "see" the problem. Otherwise, how can one decide what to do and what to expect, what is significant at any one time?

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[11] G. G. Simpson, C. S. Pittendrigh, and L. H. Tiffany, *Life: An Introduction to Biology*, Harcourt, Brace, N. Y., 1957, p. 22.

2. The observer analyzes the situation and recognizes a problem, vague or distinct.

3. He makes one or more educated guesses as to the solution of the problem. This may be called a trial explanation or working hypothesis, limited or grand, depending on the magnitude of the idea. He may formulate several alternate hypotheses ("might be's"), all equally consistent with the data available (induction).

4. Each hypothesis is checked for consistency with facts already known through prior personal experience or accepted from the reports of others.

5. Any hypotheses which pass this test must then be tested further. Careful planning results in the design of experiments or planned observations (if . . . , then . . .) to test each of the hypotheses (deduction). Conditions are sought in which two hypotheses lead to differing predicted results, this speeds the sifting of hypotheses

6 New evidence is acquired from these experiments or observations.

7. The "new concept" stated in the form of a hypothesis (or hypotheses) is either confirmed, discarded, or modified on the basis of the new evidence.

8 Any hypothesis (or hypotheses) which seems to fit the observations resulting from the experiment designed is accepted *tentatively* as a satisfactory answer to the question. The concept has been attained even though it will not necessarily be held permanently.

9. Many attempts are made to find exceptions to, or limitations of, the tentative conclusion. It is checked again and again in varying situations Confirmation (or proof of error) by other scientists is sought

10. If the conclusion continues to survive the work of other scientists, it is accepted as a useful addition to the knowledge within the field. It may still be discarded or modified whenever new evidence shows this to be necessary.

11. As more and more predictions from the hypothesis are confirmed, greater credence is assigned it. This is a gradual process, for the hypothesis always remains somewhat under suspicion. Concept attainment is never ending

One major clue to the scientist's approach is indicated in 8, 9, 10, and 11 above. It lies in a *deliberate attempt to defeat one's own conclusions Above all, scientists want to know when they are wrong.* As a matter of fact, all results are stated in such a way that they *can be* proved wrong. It often takes scientists a long time to develop the technology by which they can design an experiment which will test a hypothesis; but we can be sure that if a statement is made in such a way that a test of it is theoretically impossible, it is not in the area of science. For example, the hypothesis, "Empty space is full of a material with no observable properties," is meaningless. scientists try not to make such statements, which are impossible to prove or disprove, not for lack of the proper equipment, but simply because they never could be tested, no matter what equipment was available. Niels Bohr emphasized this skeptical attitude: "Truth is something that we can attempt to doubt, and then perhaps, after much exertion, discover that *part* of the doubt is unjustified."

explanations. First, any satisfactory explanation must account for a fair part of the available information. We do not say that *all* of the available data must support the explanation. Sometimes some of the alleged data are incorrect; and we find that investigators, for their own peace of mind, often repeat experiments of others, especially when these seem to be of major importance. Second, some of the apparently relevant data may not actually be so.[13] Successful sifting and assaying of data, determining which of them *must* fit the hypothesis, is the mark of investigative talent.

Note that we have not yet placed the scientist in the laboratory (except perhaps to check some data which seemed dubious). He has been reading and thinking, checking his hypotheses against prior knowledge and experience to see if they are inconsistent with what is already known and then against the literature to see what other scientists have reported and proposed as explanations. Only the guesses which survive these tests need then be tested directly, that is, need be stated as problems which deserve investigation. *And in this fact lies the main departure from pure empiricism.*

Testing the remaining hypotheses

A scientist tries not to waste time; that is, he tends to try to work effectively and efficiently. He tries to eliminate possibilities as rapidly as possible; he uses *if-then* reasoning. He takes each of his hypotheses and sees what it implies: "*If* this is true, *then* . . . must follow." For instance, *if* x germ causes tuberculosis, *then* the experimental animals injected with x germ should get tuberculosis, while the controls should not. He then tests these consequences by experiment or observation. (Formal logic tells us that when the "then" part of the statement, the implication, is false, the "if" part, the premise, must also be false.)

This process weeds out the alternate hypotheses rapidly. It may happen that the new observations eliminate *all* the alternatives we have; then major new ideas (concepts) are needed.

Before any scientist bothers others with his ideas and suggestions, he must carefully appraise them. He must be, as we have observed earlier, diligently self-critical. Only when he has tested his ideas again and again, and has checked them against the work of others, can he prepare the report required of him; this report is written rather like a legal brief, presenting his argument and citing supporting and limiting evidence from others. Dewey[14] long ago pointed out the great difference between the "dynamic logic" a scientist practiced in his laboratory and the "formal logic" he finally wrote in his papers. Too often we confuse the formal presentation with the hurly-burly of creative

[13] For instance, Pasteur in his study of fermentation deliberately excluded the evidence of Liebig and Wohler that oil of bitter almonds was formed from amygdalin without the presence of living things. To Pasteur this occurrence was not "fermentation properly so called." We now know that Pasteur was wrong, but note that without restricting the data to be considered he might never have achieved any solution. Later studies extended and changed his results to include what had at first seemed basically different.

[14] John Dewey, *How We Think*, Heath, Boston, 1909, rev. 1933.

Classification

Scientists simplify their many observations of the world by grouping them according to many classification systems. Any classification system, of course, is valid only to the extent that it is useful. In botany, for example, various bases for organizing the plants of the world had been used before Linnaeus proposed using the characteristics of the reproductive organs for a new system. Botanical scientists have adopted this system, but practical gardeners may be more interested in the height, color, and date of blooming of various plants, and a classification based on these observations might be valid for them. That is, each classification system is chosen to serve one end, and other systems of organizing the same materials may be used for other ends. There is nothing sacred about a classification system; its purpose is to be useful in organizing one's observations.

Grouping observations is then a major part of scientific work. Often major new concepts have followed from the introduction of novel and more useful ways of grouping data. Perhaps the most impressive example is the periodic table of the chemical elements. This patterning on the basis of limited chemical information later accommodated, even led to, much of the information on the physical properties of atoms.

Generalizing from data

Classification, then, seems to involve generalizing (or explaining) from data; this is essential to science, for it is one of the patterns of the investigator. But a scientist is necessarily skeptical, from bitter experience, of easy *overgeneralization*, "for the truth of a general proposition may be disproved by a single exceptional case." [11] (We teachers are perhaps guiltier in this respect than scientists; in our mad haste to "cover" some field of science, we daily encourage dangerous overgeneralization; see Chapter 2.)

Formulating and eliminating hypotheses

After the problem has been stated, simple guesses (or hunches) of what sort of explanation might work are generally made. These hunches arise from similarities to past experiences—the sort of explanations that have been useful for similar cases in the past. But a new problem is not likely to be answered by a simple copy of what worked in some other circumstances. Ingenuity and imagination in restructuring or regrouping the factors are important. (All too often the importance of this creative mental work is overlooked, for when "thinking" a student may not seem to be "doing" anything; see Chapter 6.) This kind of inductive detective work toward a satisfactory explanation is the essence of science.

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work. Too often we expect immature pupils just beginning to practice the rudiments of "dynamic" science to behave in the pattern of the "formal" results we read.

Translating ideas into equipment

One major aspect of scientific work often overlooked is the ability to translate an idea into equipment. A wide knowledge of available instruments and their characteristics is essential, then a choice of components and arrangement must be made. Not everyone is equally effective at this, so some scientists become specialists on instrumentation. Without careful consideration of what questions we are asking with the equipment, we may get, without realizing it, answers to questions we *did not intend to ask*.[15]

The tools we use define the operation through which we gain information. While certain man sized objects like trees and mountains may be examined as they are, our knowledge of them may remain descriptive, superficial, and static. If we wish to explain in more detail what they are composed of or how they are changing, we dissect them *physically and chemically*. But then we are concerned with invisible materials and forces revealed to us only through gross effects upon our instruments. Louis Agassiz advised his students to "observe nature"; but we must realize that for the study of invisible materials and forces, we can get answers only to the questions we ask through the arrangement of *our instruments. Every arrangement of apparatus has inherent within it* the subtle story of "how we know what we know." Our knowledge of the structure of the atom has been influenced by the cyclotron, of the composition of the stars, by the spectroscope.

Searching for precision

All our knowledge of the world begins as qualitative information (description by adjective or adverb) and it is often vague at that. Comparisons are frequently made on qualitative bases.

In some instances we want to make nice, *precise predictions*. Then we try to replace the qualitative prediction about "what kind of . . ." with quantitative predictions about "how much of. . . ." But the effort to make quantitative observations is great and is not always necessary for the prediction at hand. For example, for a storekeeper who wants a bright sign the distinction between argon and neon glow tubes can be made *simply by noting* that *argon* has a purplish light while neon is orangish (a qualitative classification). he need not specify or measure the wave lengths of the individual radiations emitted (a quantitative classification). However, for other uses it is important to know the wave lengths to a high degree of precision. Note, too, the deliberate distinction made between qualitative and quantitative chemistry.

[15] See, for example, W. B. Cannon, *The Way of an Investigator*, W. W. Norton, N. Y. 1945.

We must know that an object or reaction has certain qualitative characteristics before we can even choose whether or not to bother to determine them quantitatively.

We must always decide what degree of precision is useful for the problem at hand. There is no need to crack a walnut with a pile-driver, yet sometimes we fail to help students estimate what precision will be satisfactory for the problem being attacked. This point is exceedingly important, for as we all know, increased precision is obtained only with a severe price in time and equipment. Inevitably we are faced with the question of how exact our predictions are and how exact our tests of them need be.

Accepting a hypothesis as a theory

When a hypothesis has been found which agrees with known data, is not inconsistent with other major concepts, and does not imply false consequences, what more should we ask of it? Just one thing: Does it work? That is, does the new explanation lead to predictions that fit better with what is observed? This is what Conant meant when he defined science as "a series of concepts or conceptual schemes (theories) arising out of experiment or observation and leading to new experiments and observations." [16]

Sometimes a new explanation will be seen to account for peculiar observations which have been available but not explained previously. This often occurs after publication when specialists familiar with other sets of data suddenly see that the new idea accounts for previously unexplained observations in their field.

But above all scientists require that they know when their theories are wrong. Their theories, their explanations must be *testable*. To repeat—does it work, where, when, and how well? Reflection on these brief comments about scientific work should remind us that science is built in the minds of men.

> [Natural science] expends its utmost pains on attempting to describe the "how" fully and accurately by first hand observations. . . . What, however, it does not include within its scope and does not set itself to ask is whether that "how" is "good" or "bad" or whence that "how" ultimately derived.[17]

Making value judgments

Here Sherrington opens a fundamental topic: the role of *value judgments* in science. To claim that no value judgments are made in science would be ridiculous. Continuously the scientist selects one set of phenomena as the important one, prefers one explanation over another, is pleased when a new "beautiful" theory appears to simplify what has previously been complex. Such judgments are based on simplicity, clarity, economy, and fruitfulness; that is, they are essentially aesthetic judgments. They clearly are not moral judgments

[16] J. B. Conant, *On Understanding Science*, Yale U. Press, New Haven, 1947.

[17] Sir Charles Sherrington, *Man on His Nature*, Cambridge U. Press, N. Y., 1940, p. 2; see also our list of paperbacks, p. 551.

like those involved in theology, ethics, and religion. As Sherrington observes later, since we assume the universe to be one vast harmonious unit, the scientist would be grossly presumptuous to apply to the universe value judgments which apply only to the behavior of men toward men.

Teleology and its place in science

Teleology, an approach or frame of mind in which we assert or desire that the world be shaped toward some purposeful end, is basically a philosophical position. Often in the sciences, especially biology, some teleological element is difficult to avoid. Consider the grand implications of the theory of evolution, or the patterns of physical and chemical reactions. Many scientists, in a philosophical mood, will explore mentally the teleological implications of their work. As scientists, however, they avoid it. Teleological arguments are not part of creative science. The reason is clear. If we spend our time contemplating the "ultimate design," we never get on with the business of creating increased predictability; we may even overlook implications of our observations which do not fit our teleological position, as so many of the very early scientists did. Teleological arguments do not lead to observable predictions, they often block science.

"The problem" and "problem solving" as a key operation of the scientist

Note how we have apparently sidestepped problem solving as a "key operation" of the scientist. At last, we must face it. Why do we place (almost at the end of our discussion) that which crops up first when people discuss the way of the scientist? The scientist is the problem solver *par excellence*, is he not? He begins his investigation with a problem, does he not? The problem comes first, does it not—even as teachers place it first on the board?

What we have tried to indicate is that problem solving begins even before the problem is stated; it begins perhaps unconsciously. The specific problem may be clarified when the scientist begins the empirical or the experimental-investigative portion of his work, *but a great deal of his work goes on before he states his problem* in a formal way. The scientist solves problems, but this is not to say, we repeat, that he begins his investigation with a stated problem. It would seem, from our observations of the way scientists work, that the problem filters out of a mixture of observations, flashes of insight ("eurekas"), vague, muddled dissatisfactions, tentative essays into empiricism, reading, consultation with others, thinking (conscious or unconscious), mental scanning, and so forth. Eventually the problem does filter out, and an attempt to state it clearly is made. Clear statement is necessary if an experimental design or investigation is to be fruitful.

A scientist has long "office hours," in fact, they are almost continuous.

Like all creative people, including teachers, he does not leave his problem in the locker at the end of the day. It is always with him, and clues or answers may appear at any time. This concentration or persistency is one hallmark of the embryo scientist. Science means hard work—as does all scholarship.

The kind of *problem solving* in which the scientist participates in order to develop concepts is certainly not to be equated with the *problem doing* found in workbooks. Problem doing is the fate of the classroom demonstration or experiment which must be done, finished, accomplished, and wrapped up in the 40 minutes of a class period. Hence our own predilection for distinguishing between the problem solving of the scientist (concept seeking) and the problem doing of the pupil (concept confirming). This is not to say that problem doing has no place in science teaching; indeed it has, especially when the history of science is taught (this is, actually, the content of our present courses). But it is to say that the science class is also a place for problem solving or concept seeking. Concept attainment *can* be achieved in the science classroom (Chap. 6).

It is, therefore, in order to emphasize the need to consider the nature of what we would have students do in problem solving, rather than problem doing, that we have placed this section in the middle of our discussion of the key operations of the scientist. We want, for our purposes, to distinguish between the way of the scientist in problem solving (a creative act) and the routine of the usual problem doing of the student taking an established course, in which the solution is foreordained, because there is a rigid schedule (perhaps 40 minutes) and standard equipment. Do we want our students to engage in problem solving or in problem doing? We think both.

In problem *doing* the problem is stated first; it may even be handed down. In problem *solving* the statement of the problem is a creative act; it is a key operation resulting from much preliminary work in problem solving. It is the partial end result, as it were, of a part of the entire investigation. The scientist heaves as much of a sigh of relief in clarifying his problem as he does in reaching a hypothesis, in developing a piece of crucial equipment, or in reaching his conclusion. The problem is a *result* of "sciencing," a result of the act of problem solving, not necessarily the *cause* of it.

However, this is not to leave out the possibility of a problem occurring to a scientist in a flash of insight (the "eureka" process; see Chapter 6, Winning the Concept). But even then the problem will be refined, restated, and even discarded, as the scientist "does his damnedest with his mind, no holds barred," that is, as he develops a new relationship, as he attains the concept, as he solves his problem.

Recognizing the limitations of concept attainment

Inevitably the scientist is haunted by his acute awareness of the limited information he has. He never knows "everything" about anything. Therefore his explanations are carefully phrased in terms of certain data which them-

selves are limited in precision. More accurate data may change the picture, as in the discovery of isotopes, and new lines of information from new tools may drastically modify the best answers created to date. The discovery of radioactivity certainly altered the earlier descriptions of atoms. Dalton's idea of the atom as a solid particle underwent some remarkable transformations as Rutherford and Bohr began to "see" the atom as mostly empty space.

Scientific explanations should not involve assumptions contrary to basic conclusions widely accepted and used. For example, "flying saucers" were alleged to have been observed making abrupt 90-degree turns at speeds of 1,800 miles per hour. But such behavior is inconsistent with fundamental, widely useful laws of angular momentum and inertia. The objects we know about just do not make abrupt 90-degree turns at such speeds. Until we do observe and confirm such phenomena many times, until we "know" such phenomena, we cannot accept them as part of our rational explanation of the universe. We would prefer to hold to the generalizations about angular momentum and inertia than to abandon them in favor of "little men from Mars," at least until we have more evidence. Our growing explanations of the world must not be inconsistent.

Concept seeking—the way of the scientist and the way of his world

Science, it seems, is more than empiricism, more than problem solving, certainly more than a method, or methods, even more than an attitude: it is a use of intelligence in a very complex, and at present little understood, cerebration in an attempt to make sense of this world. Its patterns of investigation and its operations in investigation are an attempt to discover the regularities, if any, of nature. The way of the scientist is designed to determine the way the world works. "Sciencing," as Bridgman has it, is a total operation. It really has no beginning as such and no end as such. It is, in a sense, the seeking of concepts—concepts and conceptual schemes which man builds to help him understand man and the universe. One concept leads but to another.

In *On Understanding Science*,[18] Conant emphasized the cumulative nature of science in contrast to other fields of creative effort. Suppose Michelangelo, Raphael, Chardin, and Rembrandt were to come on the present scene to answer the question "Has painting advanced since our times?" We could visualize some interesting discussions, but hardly agreement. And what might Beethoven, Bach, Brahms, Schumann, and Wagner say of modern music?

What, however, would Newton, Galileo, Archimedes, Dalton, Vesalius, Grew, and Mendel say of modern science? Surely they would agree that science had advanced. And in analyzing why this advance might be so palpably clear, Conant derives what to him appears a consistently clear characteristic of scientific accomplishments. Science is both *cumulative* and *self-correcting*.

[18] J. B. Conant, *op. cit.*

In examining the work of research scientists and in analyzing their reports, Conant observes that the *end result* of a scientist's work, if indeed, the word "result" may be used, is but another problem or several, not a conclusion or a "new" discovery, but a breathing space on the way to another concept. The scientist's way is an unending quest, unending conceptualization, or unending concept attainment; science is truly an "endless frontier."

If we wish to distinguish, in a broad sense, the research scientist from the applied scientist, let us say the doctor or engineer, then the notion of the unending quest becomes useful. The engineer has an end to each specific task, for example, building a bridge; the doctor has an end in his "cured" patient; the technician has an end to his specific job with its completion.

The scientist's aim, conscious or otherwise, is a hunt for the conceptual scheme, for a spatial pattern in the infinite jigsaw puzzle of how the world works. A few such schemes (each based on many discrete facts, principles, and concepts) are given by way of illustration:

The earth is surrounded by an ocean of air.
Some diseases are caused by microorganisms.
Existing organisms are the result of evolutionary changes during the earth's history.

These conceptual schemes, which we admire and use, resulted from observation and experiment, interwoven with creative mental effort. If observations and experiments are to lead to conceptual schemes which are to be a useful picture of the real world, they need to be reliable. But since man is not always reliable, the investigations must somehow be self-correcting. How is this self-correction by unremitting investigation built into the scientist's way of work?

All men are fallible, even scientists. They, however, are acutely aware of their fallibility, as the quotation from Bridgman has shown. A major question then is how scientists dealing with incomplete and imperfect data are able to establish general statements on which they put great reliance. This is accomplished because scientists, conscious of their limitations, are inherently skeptical, in the best sense of the word, of their own work and that of others. Any single scientist's work must be confirmed. This open-endedness of an investigation, the realization that conclusions are not final, always provides opportunity for reconsideration of a result when new data become available. (New tools may play a major role in providing such new data.) The scientist must accept some ambiguity in his knowledge even as he strives to lessen the ambiguity.

Bridgman has stressed the importance of using the correct operation in making observations. This involves the appropriate choice and arrangement of tools. We would all agree that a ruler is appropriate for measuring height, but not for measuring intelligence. What constitutes the "correct" operation is always somewhat in doubt; one does the best he can and leaves to his colleagues now and later the task of criticism and improvement.

Thus scientific work is never ended; it can always be extended and im

selves are limited in precision. More accurate data may change the picture, as in the discovery of isotopes, and new lines of information from new tools may drastically modify the best answers created to date. The discovery of radioactivity certainly altered the earlier descriptions of atoms. Dalton's idea of the atom as a solid particle underwent some remarkable transformations as Rutherford and Bohr began to "see" the atom as mostly empty space.

Scientific explanations should not involve assumptions contrary to basic conclusions widely accepted and used. For example, "flying saucers" were alleged to have been observed making abrupt 90 degree turns at speeds of 1,800 miles per hour. But such behavior is inconsistent with fundamental, widely useful laws of angular momentum and inertia. The objects we know about just do not make abrupt 90-degree turns at such speeds. *Until we do* observe and confirm such phenomena many times, until we "know" such phenomena, we cannot accept them as part of our rational explanation of the universe. We would prefer to hold to the generalizations about angular momentum and inertia than to abandon them in favor of "little men from Mars," at least until we have more evidence. Our growing explanations of the world must not be inconsistent.

Concept seeking—the way of the scientist and the way of his world

Science, it seems, is more than *empiricism*, more than problem solving, certainly more than a method, or methods, even more than an attitude: it is a use of intelligence in a very complex, and at present little understood, cerebration in an attempt to make sense of this world. Its patterns of investigation and its operations in investigation are an attempt to discover the regularities, if any, of nature. The way of the scientist is designed to determine the way the world works. "Sciencing," as Bridgman has it, is a total operation. It really has no beginning as such and no end as such. It is, in a sense, the seeking of concepts—concepts and conceptual *schemes* which man builds to help him understand man and the universe. One concept leads but to another.

In *On Understanding Science*,[18] Conant emphasized the cumulative nature of science in contrast to other fields of creative effort. Suppose Michelangelo, Raphael, Chardin, and Rembrandt were to come on the present scene to answer the question "Has painting advanced since our times?" We could visualize some interesting discussions, but hardly agreement. And what might Beethoven, Bach, Brahms, Schumann, and Wagner say of modern music?

What, however, would Newton, Galileo, Archimedes, Dalton, Vesalius, Grew, and Mendel say of modern science? Surely they would agree that science had advanced. And in analyzing why this advance might be so palpably clear, Conant derives what to him appears a consistently clear characteristic of scientific accomplishments. Science is both *cumulative* and *self-correcting*.

[18] J. B. Conant, *op. cit.*

In examining the work of research scientists and in analyzing their reports, Conant observes that the *end result* of a scientist's work, if indeed, the word "result" may be used, is but another problem or several, not a conclusion or a "new" discovery, but a breathing space on the way to another concept. The scientist's way is an unending quest, unending conceptualization, or unending concept attainment; science is truly an "endless frontier."

If we wish to distinguish, in a broad sense, the research scientist from the applied scientist, let us say the doctor or engineer, then the notion of the unending quest becomes useful. The engineer has an end to each specific task, for example, building a bridge; the doctor has an end in his "cured" patient; the technician has an end to his specific job with its completion.

The scientist's aim, conscious or otherwise, is a hunt for the conceptual scheme, for a spatial pattern in the infinite jigsaw puzzle of how the world works. A few such schemes (each based on many discrete facts, principles, and concepts) are given by way of illustration:

The earth is surrounded by an ocean of air.
Some diseases are caused by microorganisms.
Existing organisms are the result of evolutionary changes during the earth's history.

These conceptual schemes, which we admire and use, resulted from observation and experiment, interwoven with creative mental effort. If observations and experiments are to lead to conceptual schemes which are to be a useful picture of the real world, they need to be reliable. But since man is not always reliable, the investigations must somehow be self-correcting. How is this self-correction by unremitting investigation built into the scientist's way of work?

All men are fallible, even scientists. They, however, are acutely aware of their fallibility, as the quotation from Bridgman has shown. A major question then is how scientists dealing with incomplete and imperfect data are able to establish general statements on which they put great reliance. This is accomplished because scientists, conscious of their limitations, are inherently skeptical, in the best sense of the word, of their own work and that of others. Any single scientist's work must be confirmed. This open-endedness of an investigation, the realization that conclusions are not final, always provides opportunity for reconsideration of a result when new data become available. (New tools may play a major role in providing such new data.) The scientist must accept some ambiguity in his knowledge even as he strives to lessen the ambiguity.

Bridgman has stressed the importance of using the correct operation in making observations. This involves the appropriate choice and arrangement of tools. We would all agree that a ruler is appropriate for measuring height, but not for measuring intelligence. What constitutes the "correct" operation is always somewhat in doubt; one does the best he can and leaves to his colleagues now and later the task of criticism and improvement.

Thus scientific work is never ended; it can always be extended and im

proved. For instance, Piltdown Man, long a debatable construct of the anthropologist, is now recognized as a classic hoax. How the fraud was finally exposed is a fine example of the self-correcting nature of scientific study. The original papers are worth reading.[19] They would serve well to illustrate many aspects of how the scientist works. They also illustrate how the scientist is constantly scrutinizing his "operations," "concepts," and "conceptual schemes." He is constantly asking:

What do we know?
How do we know it?
How well do we know it?

As a scientist consistently asks questions of this nature, he introduces a self-correcting element into his ways of work. Scientists, we repeat, can and do make mistakes. Anyone who is familiar with the history of science can cite chapter and verse. But the scientist's way is self-correcting mainly because confirmation of observation is made by many others who are free, to a reasonable extent, of the personal bias which may have influenced the original statement. In science, too many cooks do not spoil the broth. The meal is prepared by many cooks working in many different kitchens. Hence any conclusion, confirmed as it is by different men, with different intent and in different situations, tends to approximate the "truth." And hence, when the conditions are better known and the operation is appropriate, future results are increasingly *predictable*.

Predictability is a characteristic sought not only by the scientist, but also by the cook who wishes to anticipate the hardness of a three minute and of a four-minute egg. *However, the scientist is not satisfied with merely knowing* from past experience how hard the egg will be. He asks "how" this hardening occurs. From such questions, and extensive careful studies, have come conceptual schemes which are the basis of our knowledge of proteins, their properties and their molecular structure. Unlike many cooks, the scientist can explain what is happening and from that explanation can predict how other proteins will react. Furthermore, the scientist may be able to design and produce new proteins.

Attitudes of the scientist

One student of ours thought he summed up the matter by saying, "It's the business of the scientist to be honest in his work." He might have added that he must also be patient enough to suspend judgment if only because it takes time to gather facts and to test their validity. It is unnecessary to assume that scientists are honest in all their affairs, or are open-minded (in the sense of suspended judgment) in all the relationships they must assume day in and

[19] W. L. Straus, Jr., "The Great Piltdown Hoax," *Science*, 265, Feb. 26, 1954.
See also K. P. Oakley and J. S. Weiner, "Piltdown Man," *American Scientist*, 43, 573, Oct. 1955, and J. S. Weiner, *The Piltdown Forgery*, Oxford U. Press, N. Y., 1955.

day out. We are dealing with men, not supermen. We are dealing with the scientist *at work* as he searches for the discoverable regularities in nature.

Other fields of work require these same attitudes—the detective, the accountant, the judge *at work* need generous allotments of the "attitudes of the scientist." It is not these attitudes which make the scientist a scientist; it is attempting to work in science that forces these attitudes upon him.

Implicit in our whole discussion is the personal and social climate of opinion within which the individual scientist works. Certainly nowadays no scientist can work effectively shut off from contact with other scientists. What each one learns is important to others. Furthermore, informed colleagues serve as a sounding-board upon whom ideas are tested. Free exchange of information is essential. This has been called "academic freedom" but it is actually intellectual freedom for all. Also implied is the free "give and take" of criticism by a scientist's peers—others who are respected and trusted as equally well informed. The scientist is most effective in an intellectually free society.

In this atmosphere he is necessarily honest, courteous, generous, and objective. Wishful thinkers and charlatans are quickly recognized and discounted. Such a social climate, sometimes called the "climate of the laboratory," or the "idea of a university," has evolved during some centuries because the criterion of accomplishment in science is objective, open for any and all to appraise. The ways of the scientist are the ways of intelligence.

Individual scientists, being human, are not perfect in all regards, even in their scientific work. History reports that even the wisest have been skeptical of ideas like evolution, relativity, and the quantum theory, which later proved to be of such major significance. But what is important to note is that such new, even radical, ideas have been open to further study. Not for many centuries has anyone attempted to prohibit further exploration. If free expression, free criticism, and objective evaluation of a man's efforts are the major ingredients which have permitted scientific work to be so successful over the past centuries, are they not the same ingredients for which our whole society is searching?

Science as we shall use it in this book will be taken to mean, as Conant has developed it,[29] a series of conceptual schemes arising out of observation and experiment, and giving rise to further observation and experiment. And by *scientific methods* we shall mean all the operations, procedures, devices, and types of processes by which scientists arrive at these conceptual schemes. These include observation, experiment, the "educated guess," the "chance discovery," library research, trial and error, common sense, verifying hypotheses, and many others.

Science is what scientists *do*, and most, if not all, do it because it is their way of living; it is fun. And there are likely to be as many operations, and hence variations of methods and sequences of methods, as there are scientists. All of us may agree, however, that man is the only creature we know who appears able to use that "method of intelligence," the method which has

[29] J. B. Conant, *op. cit.*

resulted in the body of knowledge, of inventions, and of methods known as science.

Teaching the ways of the scientist

We began this chapter with a mention of 42 syllabuses at hand. Only one of them implies that there are many methods of science; 41 of them clearly imply that the scientific method is what we have called here "the empirical" or "try it and see" approach. Some of the syllabuses call this approach "problem solving." This tendency to simplify a complex subject, to seek a single approach to science, is understandable but it can be very misleading. Actually, as we have seen, *the highly empirical way of problem solving is but one approach of the scientist*, and it is a very slow one, used as a last resort when we have no better guides to action. And, of course, scientists seek and solve problems in order to find concepts; science might better be considered as concept seeking rather than problem solving.

The attitudes and methods of the scientist are *caught* as well as *taught*. How does one teach these things? How does the student learn to distinguish fact, hypothesis, theory, law? How does he learn *how to* define a problem, state his hypotheses clearly, and go on to design an experiment? Can the tactics and strategy of the scientist be taught at all? Chapter 2, and indeed the rest of this book, is given over to a discussion of these questions.

A short excursion into developing one's own concept of science and the ways of the scientist

1-1. As we noted at the beginning of this chapter, many qualified people have written volumes about the nature of science. Below we list a number of these books that you may find of interest. Perhaps from them, from our discussion about science, and from your own experience in working in science with children, you will want to construct your own definition of science. Perhaps you will be left as we have been, thinking that we know what is scientific and what is not, yet not being quite sure, for all the answers are not yet in. The edifice is not yet built, in our experience, edifices are subject to termites and shifting foundations—and a new architecture.

1-2. How might you create an interest in the air-pressure problem presented on pp. 15-16, in the following situations:

(a) Knowing that no student had ever seen it before?

(b) Knowing that every student had seen it before?

What possibilities does (a) present for predictions, for introducing unexpected results, for starting the search for an explanation? What possibili-

ties does (b) present for testing a prediction, for exploring the significance of varying meteorological conditions (would the can collapse on the moon, on Mars?)? What other phenomena are consistent with, inconsistent with, the explanation?

1-3. Choose several other demonstrations and explain in a similar way how they might be useful. (See the companion volumes,[21] which describe demonstrations, experiments, readings, field experiences which you may adapt to your own ways of teaching.)

1-4. Find written selections, like our selection from Redi, that might be used in class to develop an understanding of the ways of the scientist.

1-5. To what extent do you agree with this notion on the objectives a science teacher should follow?

"The teacher of science should aim at two main objectives:

(a) To get his pupils to reason about things they have observed, and to develop their powers of weighing and interpreting evidence.

(b) To acquaint his pupils with the broad lines of great scientific principles, and with the ways in which these are exemplified in familiar phenomena and applied in the service of man." [22]

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CHAPTER 2

The special climate of the science classroom:

Teaching the ways of the scientist

A note at the beginning: We may begin at the beginning by saying that the ways of the scientist, his method of intelligence, should be *caught*, not *taught*. Is this jargon, or does it have some meaning? It is a way of saying that attitudes and ways of thinking are sometimes most effectively taught by example and subtle practice; the learner "catches" them. These attitudes and ways of thinking are *lived* throughout the term of the relationship between teacher and student.

This doesn't mean that there is not to be a specified time, for example, a sequence of lessons, or even a unit, when the processes to be taught are planned consciously to be put emphatically before the students. But once that period of planned teaching is over, the processes are lived so that day in and day out, students and teacher practice them—that is, *do* them. In this sense, what is taught pervades the year's work.

More than a few experiences with honesty are necessary to motivate honest behavior; an easily angered teacher cannot create calm, dispassionate discussion. Just so, a teacher who does not have the ways of the scientist embodied in his class work, as a part of his own way of sciencing, cannot develop effectively with a class the ways of the scientist. Here, as in so many situations, the old saying holds: "What you do speaks so loud I cannot hear what you say."

Thus we emphasize making the way of the scientist a continuous part of every course, every aspect of the curriculum. Later, in Section III, we shall study the curriculum in general science, biology, physics, chemistry, and physical science, as well as other possible courses. We shall discuss the special contribution of each course, its flavor as well as its structure.

Doing an investigation in class

If a biologist were turned loose in a chemist's laboratory he would not be ready to replace any of the chemists. But he would feel at home; surely he would not feel completely lost. This is to say that laboratories have an interior decoration, an odor, a design, which strikes the same octave if not the same notes. Among the sciences there are certain ingredients common to all; these ingredients are the concomitants of the concept-seeking approach. For instance, the adherence to uncompromising accuracy, the careful statement of the purpose of the investigation, the preference for quantitative rather than qualitative predictions and results, the mistrust of our senses and the consequent attempt to seek checks and balances, the search for the perfectly controlled condition in which only the postulated cause is being investigated, the self-correcting nature of the quest for verified hypotheses, and the attitude of the scientist himself. All these are the ingredients, or operations, of the scientific approach to investigation we seek to describe.

How may these ingredients of the scientist's way be practiced in the classroom? Here are some ways which have been observed to be successful. Naturally, these are but examples. If we are correct in our position that fundamentals—whether they be skill in verbal expression, in the use of numerical expression, or in the method of intelligence—are taught pervasively throughout the school career, then whenever the opportunity arises, the method of intelligence will be demonstrated.

Teaching the "appropriate" operation

"Science" and "accuracy" have sometimes been called synonymous. This is so only if the appropriate operation is selected, and if quantitative methods are substituted for qualitative methods. (Bridgman, as has been mentioned before, has stressed finding the "correct" operation as the essence of a scientific investigation.) In demonstrating these ingredients of science, it is well not to obscure the point by making the situation too complex.

Some simple demonstrations to show the effect of the choice of the proper operation are:

1. Ask the students, "What is the temperature of the room?" Some will guess, others will suggest the use of a thermometer. Discuss why observing the thermometer is an appropriate operation if one wants a reliable figure.

2. Similarly, ask the students to determine the weight of an object by balancing it on the hand. List the weights which are the result of sensory impressions, then weigh the object. Discuss the importance of the appropriate operation.

3. Other occasions for discussing the importance of the appropriate operation occur:

a. When students first use a microscope, discuss the meaning of the word "invisible" with and without a microscope. Note the two possible meanings "not yet seen" but possibly "see-able," in contrast to "not see able" (x rays?). With an electron microscope are virus particles "seen"?

b When students first use the telescope, or study its use, discuss the meaning of the word "visible" with and without a telescope.

c. When students first use the Geiger counter, discuss the meaning of "seeing is believing" with and without a Geiger counter.

d. When students first use indicators, discuss the possibility of measuring pH with and without indicators.

Teaching the relevant observation

Sometimes the way of the *scientist* is equated with the way of the *observer*. Yet it is a simple thing to note that the scientist's observations are not helter-skelter or all-inclusive; they are selected and believed relevant; they serve the design of his experiment or they serve the purpose of solving his problem.

Students readily grasp the need for relevant observation. For instance, they would not expect the scientist who is studying polio to begin observing the structure of a bridge, or even the structure of an amoeba (unless he postulates that certain observable behavior of the amoeba relates to the solution of his problem) as a part of this problem.

In one of our classes, students became interested in the problem "Is there any background radiation in the community?" In planning the method of investigation it was decided *to try* to find evidence of radiation in the community in which the students lived and *to see* whether, indeed, there was radiation. Some students suggested that the extent of radiation also be tested in a neighboring community. Other students pointed out that, although this was Interesting, it was not relevant to the solution of the immediate problem and that such observations would not help resolve the particular question to which an answer was being sought. There was agreement that this was indeed not relevant, but, since it was interesting, some students went on with it. Many similar illustrations of ways of teaching the notions of relevance in observation will occur to the teacher. Without appropriate operations, of course, there can be no relevant observations.

Teaching the design of pertinent experiments

Many students of the scientist's ways are convinced that *the* operation which distinguishes him from any other type of investigator is an ability to design an experiment. Whichever way one looks at this ability, it seems to involve at least these three initial operations:

1. Specifying clearly the purpose and plan of the study. This is within the area called "stating the problem," but, as we have seen in Chapter 1, it is not quite that and yet more than that.

2. Suggesting one or more "possible conclusions," hypotheses which are tested. These are "educated guesses," the basis for "if . . . , then . . ." reasoning.

3. Designing an experiment, a planned series of observations under special conditions, in an attempt to test one or more of the hypotheses.

To illustrate, suppose a student were to say that exhaled air contains more carbon dioxide than does ordinary air. A profitable learning situation could be set up if the teacher were to ask whether anyone could design an experiment "to show that this is really so."

Were he to say "prove that this is so," as some teachers do, the student would resort to a textbook, or some other authority. This is a perfectly valid way of doing it. In fact most of the challenges hurled at students, such as "prove it," or "how do you know," are many times adequately answered "the books say so." To say "the book may be wrong" is hardly fair, because we do expect the student to use books as a basis for his work. And for most occasions in high school, carefully prepared textbooks are a useful base for science work.

Now we begin with specifying clearly what we want to determine. To do this, we may well ask students to state the "problem." In our experience, there is a useful way of teaching students how to state a problem clearly: we ask them *not only to state what is to be investigated, but also to state how it is to be done. By asking for the "operation," we ensure that the problem is clearly specified.* If only the "problem is stated," there is no assurance that what is to be investigated is more than a pattern of words. Assurance that the problem is understood comes when the student specifies what is to be done, that is, designs experiments.

Thus "Does exhaled air have more carbon dioxide than inhaled air?" is no assurance that the student knows what the words "exhaled air," "more than," "carbon dioxide," or "inhaled air" mean, even though he states a problem. But were he to add "Somehow we must devise an apparatus which will test in a certain specific manner the carbon dioxide content of the air we inhale and also of the air we exhale," he would be specifying clearly the purpose of the experiment and demonstrating his understanding of it.

How many different attributes of carbon dioxide might the teacher use as the basis for answering the question posed? If limewater turns milky, how does the student know this is evidence that carbon dioxide is present? In our experience, sketching the equipment needed for each possible test to be carried through for the qualitative-comparative result sought is a help in teaching students how to design the experiment.

In order to design an experiment, then, the experimenter generally goes through the process of doing the experiment in his imagination, postulates a

likely cause, and then mentally tests the possible ways of determining whether this cause is actually the one responsible for the effect observed. In short, he solves the problem without "doing" the experiment; he "does it," as it were, in his brain. His conclusion is therefore hypothetical: it is a possible conclusion, a trial explanation. In the exercise of hypothesizing, the student's knowledge, previous experience, imagination, and motivation come into play. Also acting is the teacher's skill in evoking interest (Chapter 7, Winning Participation). But in elaborating a "hypothesis" of a working idea, the student goes further than merely specifying the nature of the problem; he is "sciencing."

For instance, he may recall that cells use O_2 in oxidation and that CO_2 is the result of such oxidation; therefore, the expelled air must contain more CO_2 than the inhaled air. The postulated *cause* of the *effect* (increased CO_2 in exhaled air) is due to the activity of the cells. Therefore, if only he could obtain air which hasn't been placed in contact with living cells, and somehow test it *before* and *after*, he could compare inhaled and exhaled air for CO_2 content.

In designing the experiment, he bases the design on his "hypothesis." Somehow he must test air *before* it reaches the cells which change it and *after* it leaves the cells. In actual practice, if *sufficient time* is given, students will go through the stages and the reasoning mentioned above, and they will actually design an experimental device.

The student has in a sense designed an experiment with a *control*. A control, as students can learn to define it, is a comparative experiment with the *postulated cause removed*. The importance of teaching the *meaning* of the control cannot be overemphasized. For it is here that students sense the meaning of the *sine qua non* of science: *Scientists demand to know when they are wrong*. Testability of one's observations—hypotheses, conclusions, theories—therefore, is built into the design of an experiment.[1] Note that we use the term "design" to mean more than the selection and arrangement of hardware, design includes the chemicals and their possible reactions, the experimenter's activities during the run, selection of the particular phenomena to be noted, and the interpretation to be given if the results are as anticipated or to the contrary.

Teaching the nature of the control

The control experiment is not necessarily a part of the design of every observation (it may be so well known that it need not be repeated unless it becomes a very important part of the argument); but for clear knowledge scientists attempt to use the logic involved in a control experiment. Children may be taught the nature of the control quite early, elementary school pupils see its importance, and the general science course permits further development of its logical significance.

[1] E. Bright Wilson, Jr., *An Introduction to Scientific Research*, McGraw Hill, N. Y., 1952. Experimental design is discussed extensively in this book.

For instance, "Is moisture necessary to the growth of mold?" Youngsters will "design an experiment" in which they will expose bread and place it in a covered jar on a moist blotter. If they are then asked, "How do you know moisture is necessary?" they will eventually respond with a design in which the moisture is absent; that is, the *postulated cause* is removed from the control experiment.

Try them on similar hypothetical problems, for example:

A substance, called a catalyst (MnO_2—manganese dioxide), is said to speed up the production of oxygen from heated $KClO_3$ (potassium chlorate). Design an experiment to determine whether this is so. Students will design an experiment in which some $KClO_3$ is heated gently with and without MnO_2. How much MnO_2 gives the greatest yield of oxygen?

Many similar problems can be suggested (see the companion volumes in this series). Eventually students see that the difference between the *actual* experiment and *its control* is that in the control the *postulated cause* (moisture, or catalyst) has been removed, or held constant.

When students are given the opportunity to design experiments as a pervasive activity throughout the course, they soon begin to get the essence of the logic of the experiment.

Teaching the "worthwhile" experiment

In the introduction to this section, our two caricatures are drawn on the basis of what people think to be useful, meaningful, and worth while in teaching. One caricature of a teacher draws his problems strictly from *life;* the other draws his problems strictly from *subject matter.* What kind of experimentation is worth while—that drawn from problems deriving their essence from life, or from subject matter? We wish there were evidence, in the scientific sense, to support our viewpoint that teachers who draw from life the problems with which they deal in class do prepare students better for life than those who draw their problems from subject matter. But evidence in either direction is not available; the appropriate questions have not yet been asked experimentally.

However, one may ask, and rightly so, whether a youngster's time can most profitably be spent in devising experimental designs to answer such questions as:

What is the classification of the sea urchin?
What is the balanced equation for the preparation of Br_2?
What combination of pulleys will give us a mechanical advantage of 5?

or in answering such questions as:

What grade of engine oil is best used in winter or summer?
What is the relative effectiveness of different varieties of weed killers?
What is my blood type?

or in answering such questions as:

Can chrysanthemums flower in the spring?
Is fluoridation of water harmful?
Is heating by gas superior to heating by oil?

or in answering such questions as:

What kind of person shall I marry?
What policies shall we follow with regard to the use of atomic energy?
What shall we do with respect to race relations?
Is cancer curable?

What kinds of problems are chosen depends in part on the purposes of the school, its curriculum, and the training and philosophy of the teacher, among other considerations. But, in the main, we contend that the choice of an experimental investigation for the science class, as compared with the choice of investigation for the social science class, depends on what we consider to be the essence of science, namely, is the conclusion drawn from the experiment *testable?* As we considered in Chapter 1, the success of science has resulted from an insistence upon determining how well our answers described the world. Objective observational and experimental evidence allows all scientists to test each other's explanations. The more precise the predictions, the more precise is their testing and the clearer our acceptance or rejection of the explanations. Hunches and guesses about the working of the world are starting points, but the end is clear: We require evidence which will test our hunches An "untestable" hypothesis is essentially meaningless, for we cannot know how much to rely upon it and under what conditions it may be useful.

In many other areas of human inquiry such clear tests are not often possible. In the prediction of the outcome of an election we never can be sure what would have happened if the candidates had done something differently. No experiment is possible, because each situation arises only once. The concepts of political science and many other areas are necessarily vaguer than those of chemistry or biology because the tests of their appropriateness are vague. This is the case not because those studying these difficult social affairs do not wish for clearer evidence and tests, but because the nature of the subject and of society is such that clear tests have not yet been devised. In these areas the "sense-making process" is more difficult, for controlled experimentation is usually impossible.

In science a critical question is then: *Are the predictions testable?*

Teaching the idea of "numbers" of experiments

The moment the teacher is convinced that students have an insight into the nature of the control, it is well to introduce the element of "numbers" This is statistical reliability, to be sure, but on a very simple level and scale. For instance, a biology teacher may state a problem somewhat like this: "A scientist wants to find out whether certain bacteria cause a disease. He has

some guinea pigs which he knows are likely to get the disease. What should he do?"

The students will generally say, "Let him inject one guinea pig with the bacteria, and not inject another, the control." (Later, students may learn such refinements as the use of litter mates, i.e., genetically constant material.) So far so good; they "know" the nature of the control.

Now the teacher asks, "Can you be sure that all other guinea pigs will react in the same way as this one does?" Students will generally suggest another pair of guinea pigs. In a little while, students realize the need for a sufficient number of experiments in order for an experimenter to come to dependable conclusions. When we deal with laboratory work (pp. 138-143, 276-280, 486-487), we shall see that one of the advantages of laboratory work is that the entire class confirms its own experiments by designing them with adequate controls and in adequate number.

However, visualize almost any classroom in this country, or in any other, if the accounts of observers who travel internationally are correct; we are likely to see something like this:

Chlorophyll is removed from one geranium leaf. When the leaf is stained with iodine, it turns black—a test for starch. Conclusion to be accepted by the students: *all* green plants make starch.

But we have only one test of one leaf; we do not know anything about *all* green leaves. Only after testing many kinds of leaves—red oak, pine needles, elodea, algae, moss, and so on—might we hazard a guess that "probably" all green leaves make starch. A laboratory exists for such explorations.

The position of a teacher who tells students, "You can accept the generalization on my say-so," or "the textbook's say-so," is awkward indeed. This is a kind of authoritarianism, yet the scientist remains the enemy of all authoritarianism.

If the reader thinks back to his experience in the high school classroom, he will probably recall that demonstrations (they were called "experiments") were performed *once*. Wasn't a conclusion generally reached from *one* demonstration? Isn't this commonly true of science teaching today?

It is, unfortunately, a common occurrence. Yet most science teachers believe and say that, in the establishment of scientific information, the phenomenon should be observed many times under similar, and then under different, deliberately changed, conditions. As Brownell and Hendrickson [2] have said, "No child should be permitted from a single laboratory observation to formulate a generalization. . . . Instead, both in deriving a generalization and in applying it, learners need to encounter other instances of its validity; and the more practical, concrete, and natural or everyday such encounters are, the better." They also said: [3] "Children need to know not only what concepts

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[2] National Society for the Study of Education, *Forty-Ninth Yearbook*, Part 1, *Learning and Instruction*, U. of Chicago Press, Chicago, 1950, p. 121.

[3] *Ibid.*, pp. 115-16.

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[3] *Ibid*., pp. 115-16.

are (what they include, to what they refer) but also what they are *not*. The time it takes to clear up misunderstandings is amply repaid."

If conclusions are continually elicited solely on the basis of one observation, one trial, we cannot expect the pupils to see the need for, or believe, that scientists actually conduct many experiments, make many observations, and are cautious in coming to conclusions. The difference between "what I do" and "what I say" does not sit well when students must come to accept (believe) a fair-sized conclusion every hour.

Yet what is the teacher to do when he is always working within a limited time? How can he immerse the class in *one* major activity of scientists—that of designing an experiment, then checking predictions by doing it? How can he rid his instruction of chalk talk and avoid the error of the single-shot activity leading to an all embracing conclusion?

A tentative solution—use your laboratory. The first few classroom demonstrations in the year can be made the occasion for developing the idea that each represents many similar ones that have been done before. At that time the point can be made that especially important problems will be studied more fully in the laboratory, with possible variations in the kind or in the amount of materials. This statement must, of course, be followed up with the performance it promises. The teacher can stress that a demonstration, followed by individual laboratory work or not, is only an *example* of how scientists work. Time and materials permitting, the teacher should attempt to submit the most important problems to fuller laboratory experimentation.

As students continue to design experiments throughout their high school experience in science, they begin to get a glimmer into the ways of the scientist. They get a glimpse of the scientist at work, or our "method of intelligence."

Time to investigate—time to design and do experiments

Any science teacher who daily meets a class and yearly confronts an overcrowded syllabus will wonder when students may have the time to design and do the kind of experiment we have been talking about. There are several answers relating to practicable modifications of present courses of study to give more time to leisurely teaching—a prerequisite and perquisite of effective science teaching. The modifications will be dealt with in various sections in this book. Nevertheless, the teacher who is aware of the opportunities in class situations may grasp such opportunities as often as he wishes. The following is such an instance.

The "problem" situation; the opportunity grasped

Sometimes, and it can happen at least once during the year's work, a problem situation occurs. Then a teacher who believes in teaching "science" as well as "history of science" grasps the opportunity. So do his youngsters.

Here is the story of such an occasion, described in an "open letter" received by one of the authors.

The June, 1948, preliminary Science Regents contained the following question:

"Explain how you could test the truth of one of the following statements:

a. Cut flowers will not fade so rapidly if an aspirin tablet is dissolved in the water in which they are kept.

b. Hot water freezes sooner than cold water.

c. Water heats faster in a black kettle than it does in an aluminum kettle."

As a follow-up, the students in my 8th grade classes set up experiments at home to test part b. 81% of the students reported that for complete freezing hot water froze first. Out of curiosity I continued the experiment with succeeding classes. Each time I increased the controls and eliminated possible errors. The results were always the same. From 85 to 95% of the pupils found that the hot water froze sooner.

The experiment was performed in two ways:

1. Equal volumes of boiling (100° C) and cold (18° C) water were placed in separate ice trays, set side by side, and tested. The experiment was repeated with the positions of the hot and cold water trays reversed.

2. Equal volumes of water were tested as above, first cold, then hot.

The evidence for the hot water freezing sooner is as follows:

1. 903 students performed the experiment. They were instructed in reading the meniscus of a liquid, in checking temperatures of both liquids and the interior of the freezing compartment, in controlling the checking procedures, in using different amounts of water, etc. 872 students found that the hot water froze earlier.

2. With the aid of the home economics department, experiments under laboratory conditions were performed. Here are some of the typical results:

Volume (ml)	*Temp. (°C)*	*Weight (gm)*	*Time (min)*	*Freezing temp. (°C)*	*Ice weight (gm)*	*Remelted volume (ml)*
50	72	48.20	09.15	1.8	47.5	47
50	19	49 45	10 01	0.3	49 1	49
100	70	96 35	17·50	1.7	94.2	93
100	19	99.20	21:04	0.2	97.3	96

3. I checked through scores of chemistry and physics texts. There was no mention of this particular problem, although one book, *A Brief Course in Physics* by Earls (Prentice-Hall, 1949), stated that the freezing point of boiled water was higher than that of cold water which, of course, contained dissolved air.

4. Hot water weighs less than cold water. There are less grams to freeze.

5. Rapid evaporation, hence rapid cooling, proceeds quite vigorously above the hot water ice tray because it presents a large surface area and because the water is quite hot. This leads to two assumptions:

a. In the early stages of cooling the hot water is aided in its "chase" of the "handicapped" cold water by rapid evaporation.

b. Some of the hot water is lost to the sides of the freezer compartment in the form of frost, thus further reducing the number of grams in the hot water tray.

6. Tables in the *Handbook of Chemistry and Physics*, 1954-55, page 2079, show that the thermal capacity for air free water is not the same at each degree:

Temp (°C)	Thermal capacity (cal/gm/C°)
0	1.00738
5	1.00368
55	.99895
64	.99988
100	1.00697

It would appear that the hot water would be given a "cooling boost" as it fell in temperature through the middle degrees.

In any event, the class concluded that, under similar conditions, equal amounts of hot water freeze sooner than equal quantities of cold water.

Kenneth Dunn, Science Department
Carle Place High School, Carle Place, New York

(Perhaps the following comment may be relevant: Hot water will melt through the film of ice on the freezing tray and will make better contact with the freezing unit. The cold water tray may be insulated by a layer of ice which has a lower thermal conductivity than does the material of the freezing shelf.)

Kenneth Dunn grasped the opportunity to teach the design of an experiment. The class, as we understand it, worked hard but the students also had fun. Science is fun, as well as hard work; it is also an important human activity.

Observing a total scientific operation

Total scientific operations can be observed only where they are in process, and they are going on all the time in the laboratories of the nation. It may be difficult for most youngsters to observe a scientist at work, yet it can be done.

Observing scientists "in the flesh"

Wherever students get the opportunity to meet scientists or to work for them, the experience is of value to both. The scientists involved learn about the schools and are stimulated to help the science teacher by offering equipment and by appearing before science clubs and student assemblies. In one school situated near a university, students acted as laboratory assistants in minor tasks at first, and later, in advanced ones. In another school situated near a hospital, students assisted part time in the laboratories. Similarly, in several schools located in large cities where national or state conventions of scientists were held, the students were regularly sent to the meetings. In all these cases they reported on the activities of the scientists for their classmates, science club members, the school paper, and the school magazines. Also, one of the scientists at such a convention, or from such a laboratory, may be willing to come to the school and speak at an assembly.

One of the most fruitful ways for students to get direct information about the activities of scientists is to ask a former student who is majoring in science at a university to return from time to time and report on the activities there. Former students in science returning to their previous haunts have a healthy and stimulating effect on the student in school, for developing strong motivation is still a function of the school.

Observing scientists "vicariously"

As has been stated, it is not always possible to study the scientist and his ways directly, but it is usually possible to study his ways by studying his life through a biography, a film, or the "case study" approach. By these means it is possible to study the way scientists get problems, fashion their grand and limited working hypotheses, design their experiments and develop their conceptual schemes, and evolve the questions they ask of nature. After all, the most important attribute of the scientist is not that he finds the right answers but that he finds the right questions. (As we developed in Chapter 1, this activity of finding the right questions occurs in the brain; and there is no present verifiable knowledge as to how it occurs.)

Through biographies. Reading biographies of scientists is apparently very useful in getting at their way of approaching and solving problems. For instance, Hans Zinsser's account of his life in *As I Remember Him*, Vallery-Radot's *The Life of Louis Pasteur*, or Eve Curie's account of her mother's life, *Madame Curie*, help the student glimpse the tragedies and triumphs of a scientist's life. They get a bit of the smell of the laboratory, they see imagination and gather information, they get an inkling of the scientist as scientist and as human being.

Through motion pictures. It is now possible to get several films useful in giving youngsters a miniature of the scientist. For instance, *Louis Pasteur*, *The Magic Bullet* (a vignette of Paul Ehrlich), or *History of Chemistry* will help youngsters to get some insight into the nature of scientific work.

Lists of such films may be found in the companion volumes (see footnote on p. 33); some of these films are available on loan.

By a study of their papers. One of the methods the scientist uses, highly typical of his approach, is publication of data. He intends, unless he is bound by security regulations, to make his knowledge available to all. And he describes his methods in such a way (in a "formal logic") that they may be confirmed by others. Hence his paper is part of the self-correcting method of the scientist.

It is entirely possible (and it has been done) for a teacher to get a set of research papers by writing to scientists asking for reprints. However, he should make his requests reasonable, and remember that someone, often the scientist, had to pay for the reprints. (Perhaps he need request only one, and can mimeograph copies.) These reprints may be examined in class and the organization discussed. For instance, general headings such as: (1) Introduc-

tion, (2) Method, (3) Observation, (4) Conclusions, and (5) Bibliography.

As a result of a study of such papers youngsters "catch" the climate of accuracy, carefully detailed work, and essential honesty of the scientist's efforts. They catch, in short, something of the *attitude* of the scientist. They can see something of the way the scientist uses guesswork, common sense, trial and error, as well as "imagination" to get at a solution to the problem. They will also see, if the reprints are wisely chosen, that unsuccessful as well as successful experiments are reported.

Through the case method. Students of law or business administration often study cases dealing with specific important generalizations and analytical operations in these fields. Students of science can also profit from the use of case studies in science. In fact, several large universities, including Chicago, Colgate, and Harvard, have used cases for some of their general education courses in science. The intent is to have the student, through the study of relatively simple factual material, follow closely from the original writings the way in which the scientist tried to reshape his material and ideas to reach some major conclusion. Conant has called this "looking over the shoulder of the scientist at work." The student should recognize through his own experience the difficulties and procedures of the scientist at work.

Several high school science teachers have also for many years used cases in their instruction. The materials chosen are less lengthy and complex than those used in college, but the intent is the same.[4] A series of experimental cases for use in high schools is now being developed. The first titles are: *The Sexuality of Plants, The Discovery of Bromine*, and *How Far Away Is the Sun?* Each is chosen to illustrate clearly certain aspects of scientific creativity. A number of high school texts also include sample case histories.

The Harvard Case Histories, available in pamphlet form,[5] are:

1. J. B. Conant, *Robert Boyle's Experiments in Pneumatics*
2. J. B. Conant, *The Overthrow of the Phlogiston Theory*
3. Duane Roller, *The Early Development of the Concepts of Temperature and Heat*
4. L. K. Nash, *The Atomic-Molecular Theory*
5. L. K. Nash, *Plants and the Atmosphere*
6. J. B. Conant, *Pasteur's Study of Fermentation*
7. J. B. Conant, *Pasteur's and Tyndall's Study of Spontaneous Generation*
8. Duane Roller and D. H. D. Roller, *The Development of the Concept of Electric Charge*

While these cases are likely to be too complex for secondary school pupils, they are admirable for use in teacher training institutions.[6]

[4] L. Klopfer and F. G. Watson, "Using Historical Materials in High School Science Teaching," *The Science Teacher, 24*, 264, 1957.

[5] Harvard U. Press, Cambridge, various publication dates, list prices vary from about one to two dollars.

[6] Other useful examples of cases are available in I. B. Cohen, *Science, Servant of Man*, Little, Brown, Boston, 1948, and W. I. B. Beveridge, *The Art of Scientific Investigation*, rev. ed., W. W. Norton, N. Y., 1957.

Each case study is built around significant sections from the original writings of the scientists involved. There is an analysis of the historical background behind each investigation and a painstaking account and analysis of the investigator's purpose, his way of recognizing the problem, his grand and limited working bypotheses, his experimental design, his techniques, his errors, and his difficulties.

The essential way of dealing with the case study is to have students read it before class, then "milk it dry" with a discussion of the ways of the specific scientist under scrutiny. At Forest Hills High School, for example, George Schwartz uses mimeographed excerpts of the actual papers of the scientists involved in the development of the concept being discussed. For instance, in a discussion of spontaneous generation, his students are given a translation of a portion of Francesco Redi's experiment (p. 17) and a part of Pasteur's as follows:

PASTEUR PROVES THAT FERMENTATION AND PUTREFACTION ARE BROUGHT ABOUT NOT BY THE AIR BUT BY PARTICLES SUSPENDED THEREIN [1]

I believe I have rigorously established in the preceding chapters that the organized productions of infusions that have previously been heated have no other origin than the solid particles which the air always carries and constantly lets fall on all objects.

If there can still remain in the mind of the reader even the least doubt in this regard, it will be removed by the experiments of which I am about to speak.

I place in a round glass flask one of the following liquids, all of which are very easily altered by contact with ordinary air: watery extract of yeast, sweetened watery extract of yeast, urine, beetroot juice, watery extract of pepper; then I draw out, at the blowpipe, the neck of the flask so as to give it various curvatures as is indicated [accompanying figures]. I then bring the liquid to a boil for several minutes until the steam issues freely from the open end of the drawn-out neck, using no other precaution. I then let the flask cool. It is a remarkable fact, calculated to astonish anybody who is used to the delicacy of experiments relative to so-called spontaneous generations, that the liquid in the flask remains indefinitely without alteration. One can handle the flask without apprehension, move it from one place to another, allow it to undergo all the temperature changes of the seasons, and the liquid in it shows not the slightest alteration and keeps its smell and taste. . . . There will be no change in its nature other than, in certain cases, a direct oxidation, purely chemical, of the matter. But we have seen by the analyses which I have published in this memoir how this action of oxygen is limited, and that in no case are any organized productions developed in the liquids.

It appears that the ordinary air, returning with force at the first moment, must reach the flask quite unaltered. That is true, but it encounters a liquid that is still near its boiling point. The re-entry of the air thereafter occurs more slowly, and by the time that the liquid is so far cooled as no longer to be able to deprive germs of their vitality, the re-entry of the air becomes so slow that it leaves behind, in the damp curves of the neck, all the dust particles capable of acting on the

[1] F. Sherwood Taylor, *A Short History of Science and Scientific Thought*, W. W. Norton, N. Y., 1949, pp. 206-07.

infusions and bringing about the production of organism. At least, I see no other possible explanation of these curious experiments. If, after one or many months' stay in the incubator, the neck of the flask be detached by a nick with a file, without touching the flask in any other way . . . after twenty four, thirty-six or forty eight hours, molds and infusoria begin to show themselves absolutely in the ordinary way or just as if one had sown dust particles from the air in the flask.

In class, a discussion brings out the essential purpose, method, and outcome of the experiments, as well as the way of the scientist—all this, of course, in addition to background reading in the text.

For instance, note how the spirit of Jan Ingen-Housz's investigations is disclosed even on a brief reading of the excerpts which follow:

EXPERIMENTS UPON VEGETABLES DISCOVERING THEIR GREAT POWER OF PURIFYING THE COMMON AIR IN THE SUNSHINE, AND OF INJURING IT IN THE SHADE AND AT NIGHT[8]

I was not long engaged in enquiry before I saw a most Important scene opened to my view: I observed that plants not only have a faculty to correct bad air in six or ten days by growing in it, as the experiments of Dr. Priestley indicate, but that they perform this important office in a complete manner in a few hours; that this wonderful operation is by no means owing to the vegetation of the plant, but to the influence of the light of the sun upon the plant . . . ; that this operation is far from being carried on constantly, but begins only after the sun has for some time made his appearance above the horizon, and has, by his influence, prepared the plants to begin anew their beneficial operation upon the air, and thus upon the animal operation, which was stopt during the darkness of night; that this operation of the plants is more or less brisk in proportion to the clearness of the day, and the exposition of the plants more or less adapted to receive the direct influence of that great luminary, that plants shaded by high buildings, or growing under a dark shade of other plants, do not perform this office, but, on the contrary, throw out an air hurtful to animals, and even contaminate the air which surrounds them, that this operation of plants diminishes toward the close of the day and ceases entirely at sunset, except in a few plants, which continue this duty somewhat longer than others; that this office is not performed by the whole plant, but only by *the leaves and the* green stalks that support them; . . .

This work is a part of the result of above 500 experiments, all of which were made in less than three months, having begun them in June and finished them in the beginning of September, working from morning till night.

EXPERIMENTS SHOWING THAT PLANTS HAVE A REMARKABLE POWER TO CORRECT BAD AIR IN THE DAY

56 A sprig of peppermint put in a jar full of air fouled by breathing (so as to extinguish a candle), and exposed to the sun, had corrected this air in three hours so far that a candle could burn in it.

57. A sprig of nettle was put in a jar full of air fouled by breathing so as to extinguish a candle; it was placed in a room during the whole night; next morning the air was found as bad as before The jar was put at 9 in the morning in the sunshine; in the space of two hours the air was so much corrected that it was found to be nearly as good as common air.

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[8] Jan Ingen Housz London, 1779.

Experiments showing that the sun, by itself without the assistance of plants, does not improve air but renders it rather worse

12. Two jars, half full of air taken from the atmosphere at the same time, and half full of pump water, were left by themselves during four hours; the one was exposed to a bright sunshine, the other placed within the house, only two steps from a door opening in the garden. The air kept in the house gave, in six different trials, constantly the appearance of being better than that of the jar placed in the sun One measure of the air kept within doors with one of nitrous air occupied 1.06½, whereas that exposed to the sun occupied 1.02½. I must, however, acknowledge that this experiment ought to be repeated more than once, to put the fact out of any doubt. I made it the very last day of my stay in the country, and thus had no time to repeat it.

Experience with a number of teachers has indicated that the case study method is exceedingly uselul especially when library facilities are available. Further discussion of methods of teaching science in later chapters will offer further approaches which make use of the case method.

Through scientists' evaluations of their own methods. Scientists are not illiterate. In fact, many times they make statements which describe how they think, feel, appraise, or evaluate their own methods of work. Sometimes these evaluations are brief but comprehensive statements. An examination of even a few brief quotations will indicate that valuable discussions may result from their analyses.

What is science?
its sources, aims, and procedures [9]

This is the first fact about science: it is a human activity. As such it is subject to all the frailties of human endeavor. Its history is a history of errors, slowly corrected; a history of effort, a search for a wider knowledge of facts and deeper, more embracing schemes for understanding and explaining them. Science is not a cold, infallible, impersonal machine; it is not just a collection of formulas and technical terms about abstruse questions remotely related to everyday life and thought. Science is ultimately refined common sense. It is the organized knowledge developed and possessed by men and women of the world they live in.

As a human endeavor, science is dependent on human motivation. The motivations for scientific endeavor are not hard to find. First, there is the ever-present need for knowledge that helps man master the environment he lives in, making it subservient to his needs. Our koowledge of astronomy began its growth impelled by the need of a calendar for the season-conscious Babylonian farmer. In our own day, the growth of knowledge of nuclear physics has been impelled in part by unhappier but no less practical considerations.

Secondly, and in the long run more important, there is the almost universal curiosity in men which seeks satisfaction in knowledge of the world for its own sake—knowledge not only of the facts themselves but of how they are related and how things are caused; in short, knowledge of how the world of fact can be explained and so understood. The simple and naïve questions of the small child when they recur in mature minds are the life's blood of science. "Who dug it?" as a question on first seeing the Grand Canyon is naïve only in phraseology; in

[9] G. G. Simpson, C. S. Pittendrigh, and L. H. Tiffany, *Life: An Introduction to Biology*, Harcourt, Brace, N. Y., 1957, pp. 18-19.

the older man this child-question leads to our understanding of the cutting power of running water. Cats may be killed by curiosity, but science dies for the lack of it.

Or a view of mathematics. [10]

> Mathematics, rightly viewed, possesses not only truth, but supreme beauty—a beauty cold and austere, like that of sculpture, without appeal to any part of our weaker nature, without the gorgeous trappings of paintings or music, yet sublimely pure, and capable of a stern perfection such as only the greatest art can show. The true spirit of delight, the exaltation, the sense of being more than Man, which is the touchstone of the highest excellence, is to be found in mathematics as surely as in poetry. What is best in mathematics deserves not merely to be learnt as a task, but to be assimilated as a part of daily thought, and brought again and again before the mind with ever renewed encouragement. Real life is, to most men, a long second best, a perpetual compromise between the ideal and the possible, but the world of pure reason knows no compromise, no practical limitations, no barrier to the creative activity embodying in splendid edifices the passionate aspiration after the perfect from which all great work springs.

Or even a very brief remark, such as the following: [11]

> The white man drew a small circle in the sand and told the red man, "This is what the Indian knows," and drawing a big circle around the small one, "This is what the white man knows." The Indian took the stick and swept an immense ring around both circles: "This is where the white man and the red man know nothing."

The student as "scientist"

High school students are not scientists, but they are scientists in the making. Some of them will be scientists, all of them as youngsters or adults will use some of the ways of the scientist.

If the ways of the scientist are taught pervasively during the year, the student will have the opportunity to do the various things which characterize the scientist. He will be given the opportunity to:

1. Use his imagination to develop ideas (even wild ones; wild ideas eventually succumb to the quiet of thought).
2. Design experiments, and in so doing learn to
    a. specify his problems,
    b. clarify his hypotheses,
    c. rectify his observations,
    d. verify his conclusions.
3. Give reports to his classmates (a seminar situation).
4. Do "research" in the library and the laboratory.
5. Write a paper.
6. Report before his peers (in the science class or in a Science Congress).
7. Exhibit before his peers (in a Science Fair).

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[10] Bertrand Russell, *Mysticism and Logic*, Barnes & Noble, N. Y., 1954, p. 14.
[11] Carl Sandburg, *The People, Yes*, Harcourt, Brace, N. Y., 1936.

The teaching method and techniques by which these are to be accomplished belong properly in Section III of this book. A course in advanced science wherein students do "research" projects will be described in Chapter 3 and in more detail in Chapter 9.

Here it is sufficient to indicate that a good method, possibly the best, of helping the student to understand the way of the scientist is to have him live the life of the scientist, as best he can.

Scientists and science teachers as human beings

As has been said, scientists have been successful. Although this success has been tinged with remorse for some of the social uses to which scientific discoveries have been put, still it is envied. So we find, for instance, advertising becoming "scientific"; toothpastes, lipsticks, cigarettes must somehow be associated with SCIENCE.

The result of all this has been to forget that the scientist is a human being as well, happy and troubled, with the goals and aspirations of all human beings. Indeed Kubie[12] has emphasized the price a scientist might pay for his choice of a life of research:

> Scientific research is conducted largely behind closed doors, and the accuracy of any man's observations and the veracity of his reports depend ultimately upon his honesty. This honesty depends in turn upon maturity, upon some degree of security, and upon a sense of identification and fellowship with competitors. Under present conditions, it is a tribute to scientists that violations of their code of honor are so rare that when lapses occur they become historic scandals. This issue is especially delicate in such fields of science as psychology, psychiatry, and psychoanalysis, in which it is difficult to repeat another man's observations for purposes of objective clinical or experimental or statistical confirmation.
>
> . . . Certainly the idyllic picture of the innocent, childlike scientist who lives a life of simple, secure, peaceful, dignified contemplation has become an unreal fantasy. Instead, the emotional stresses of his career have increased to a point where only men of exceptional emotional maturity and stability can stand up to them for long, and remain clear-headed and generous-hearted under such psychologically unhygienic conditions. Thoughtful educators are beginning to realize that the socio-economic basis of the life of the scientist must be entirely overhauled; that the psychological setting of his life needs drastic revision, and that, at the same time, the emotional preparation for a life of research is at least as important as is the intellectual training.

In any event, for the teacher this means that he must assume the responsibility for guidance so that youngsters might know the kind of life the scientist leads. Biographies sometimes hide the daily routine, the tediousness of investigation; they emphasize results rather than the thousands of disappointing failures and frustrations. Invite an investigator to talk candidly to students—to those who want to be scientists, and to those who do not. The

[12] L. S. Kubie, "Some Unsolved Problems of the Scientific Career," *American Scientist*, 42, 112, 1954.

latter need to understand the kind of man who gives his life over to investigation.

As we noted earlier, perhaps students who are now in graduate school and who have returned for a visit will speak to classes in science. In this way, a line of communication can be maintained between youngsters preparing to go into science, those who will need to understand the nature of science and scientists in a "scientific" age, and those who are already in the thick of investigation.

A word about transfer of training. There is little evidence that the need and the act of becoming a scientist per se makes a youngster a better person. Indeed, it seems that youngsters in high school who intend to become scientists have already achieved a type of "behavior pattern" which predisposes them to the intellectual wave lengths of life.[13] It appears, too, that youngsters who enter upon an intellectual life must develop bread-and-butter behaviors and attitudes which are part of the pattern of life they have assumed; hence, they are bound eventually to differ from those who have, let us say, assumed the pattern necessary to success in business.[14]

Nevertheless, it is conceivably sound to say that the science teacher plays a part in helping the youngster identify himself with a pattern of behavior which has been identified with the scientist.

The teacher, being *in loco parentis*, can at least approach the pattern of living he seeks to establish in the lives of youngsters. There are indeed attitudes which are helpful for scientists to assume, if only to help them get at their investigations with a minimum of emotional friction. These attitudes have been generally grouped together as "scientific attitudes." Actually they are characteristic of the judicial temperament. They are part of the method of intelligence we have been talking about. Surely it is intelligent to suspend judgment, to be open minded, to be honest and patient when one attempts to solve any problems.

It is specious, then, to allot these attributes to the scientist alone when even casual thought will show them to be necessary to wise, gracious, and balanced living. Nevertheless, a teacher who is not open minded, who is bigoted and prejudiced, who is not honest, judicious, and patient in his dealings with his students and the problems in class, cannot with propriety "teach" these attitudes or help make them active attributes. To make a mistake is human, but to admit it is also human, and some would say it is the better part of making the mistake. The fact is that scientists do make mistakes, as scientists and as human beings. As human beings their method of intelligence is fast becoming a goal and aspiration of right action. As scientists their mis-

[13] R. D. MacCurdy, "Characteristics of Superior Science Students and Their Own Sub-Groups," *Science Education, 40*, 1956, p. 3.

P. F. Brandwein, *The Gifted Student as Future Scientist*, Harcourt, Brace, N. Y., 1955

[14] Lewis Terman, *Scientists and Nonscientists in a Group of 800 Gifted Men*, Psychological Monographs, Vol. 68, No. 378, 1954, also "Are Scientists Different?", *Scientific American, 192*, Jan. 1955, pp. 25-29.

takes are corrected, for their method of intelligence serves them in an undertaking where the free, even joyful, experience in search of meaning is the central goal, and where the atmosphere of self-correction prevails. They breathe, in short, the climate of science.

This atmosphere, this climate, is also that of the science classroom. Where the method of intelligence prevails, science is "caught" as well as "taught." The science teacher clearly has prime responsibility for what goes on in his classroom; hence he has responsibility for the climate in which he teaches.

A short excursion into appraising activities appropriate to developing a climate of science

Four laboratory exercises and experiments are offered below for your evaluation.

(a) MEASURING BUOYANCY

1. Set up the apparatus as shown on the blackboard. Use any weight such as a rock or a metal object that fits into a can. Measure the weight of the object. Its weight is . ... grams. Fill the can with water until it pours over the spout. Pour out the excess that flows into the overflow can. Lower the object into the water as shown in B and note its apparent weight. The apparent weight in water is .... . The object seems to have lost . .. of weight. The buoyancy of the water on the rock is . . . What seems to be the connection between buoyancy and loss of weight? ..

2. Weigh the water displaced by the object as follows The weight of the catch bucket with the overflow water displaced by the object is . . The weight of the catch bucket when empty is . ... How does this weight of overflow (displaced) water compare with the buoyancy on the object? .

3. Repeat the experiment for another object. The weight of the new object is ..... The apparent weight in water is . The loss of weight (buoyancy) is . .. The weight of the catch bucket with displaced water is .... The weight of the catch bucket alone is .. . . Therefore the weight of the water displaced by the object is . How do the buoyancy and weight of displaced water compare? ...

4. Repeat the above experiment, using the same object as in the previous experiment but with some other liquid such as salt solution or alcohol. The weight of the object is . . The apparent weight of the object in the liquid is .... The buoyancy (loss of weight) is ... The weight of catch bucket and displaced liquid is . . The catch bucket alone weighs . . Therefore, the displaced liquid weighs . How does the weight of the displaced liquid compare with the buoyancy of the liquid on the object? .....

Arriving at your conclusions. State a hypothesis connecting the buoyancy of a liquid on an object immersed in it and the weight of liquid displaced by the object ... .

(b) WHAT IS A CONTROL EXPERIMENT?

Is moisture needed for mold to grow on bread? Set up an experiment with a *control* to answer the question above.

Here are some suggestions. My procedure: (1) Expose a slice of bread to the air until the bread is dry. (2) Break the bread into two pieces. (3) Moisten one

piece, leave one piece dry (4) ______ (5) ______
My observations of the results: ______
My conclusions ______

(c) WHAT CONDITIONS ARE FAVORABLE FOR THE SPOILAGE OF MILK?

The plan for my experiment ______

______

What happened: ______

Conclusion.* ______

* Did classmates with experimental plans like yours get the same results? It is good procedure to check results with the conclusions of others. Scientists do not accept conclusions which come from doing an experiment just once

(d) The experience described on p. 44 under the heading, The Opportunity Grasped

2-1. Which of these is most appropriate to the climate of science you would like for your school? Or perhaps you would prefer a balance? What balanced combination of these four science activities would serve your needs?

2-2. Perhaps you will want to ask yourself the same questions about the activities in Chapter 7, Winning Participation; Chapter 8, The Science Shy; and Chapter 9, The Science Prone.

Section Two

PATTERNS IN TEACHING SCIENCE

Surely the climate which exists in a science classroom depends on the science teacher. However, it does not depend on him alone. No teacher is an island, he works in a school and is subject himself to that particular and special environment with a climate all its own—the school. The school may have a pattern which is clearly traditional, college preparatory, the student behaves-or-else-and-no-monkey-business; or it may have one which is permeated with the permissive, nonthreatening climate which permits considerable variation in personal teaching pattern, or it may be anywhere between these extremes.

Let's face it. Not all teaching assignments, not all teaching tasks have noble or uplifting purposes. Not all teaching posts have liberalizing influences. Many factors determine what kind of pattern can be successful in a certain school, and what kind of pattern can be developed.

For instance, "who" is in the class—science shy or science prone, rural or urban, male or female, academically oriented or "just waiting to become sixteen"—must strongly influence what subject matter and what method is chosen to stimulate learning. A young teacher may be strongly influenced in his pattern by his early choice of a school, its intent, and the goals of the students enrolled.

In this section, various patterns of teaching will be dealt with. We have observed them all, and our prejudices, our leanings will clearly show if only because we are human, and not all-wise or all-seeing. Even if we were all-wise and all-seeing we should still present these various patterns, because teaching is a personal invention and the teacher develops his own, very personal pattern.

We might have begun with objectives or with the psychological base of concept formation. But we prefer first to examine existing patterns in classes and patterns of teachers; then the reader can more realistically appraise his own methods and purposes, determine his objectives, and make his plans for the development of students. Then we continue to the science lesson per se as given to heterogeneous groups, the science shy, and the science prone.

Then, having discussed the various patterns of science teaching in this section, we go on to apply them to specific courses in the next section. Such an approach gives us a better basis for appraising courses and curriculums.

CHAPTER 3

Patterns in teaching science:

Science classes

A note at the beginning: When a science teacher is asked, "What do you teach?", the answer is sometimes "science," sometimes "chemistry." Usually the answer involves some area of subject matter. Rarely is the answer "children," and properly so, for this answer by itself is meaningless.

Yet we do teach children. We teach them in a class, and we also teach them singly. But we always teach them *something*, even if it is only our personal attitudes toward life.

Generally as science teachers we teach science to a class, not to individuals. Yet we know that the learning which is to result from our teaching must occur individually in each separate child. We are then faced with teaching a class so that each pupil learns individually. This is a sizable problem. For essentially science teachers in the United States teach science to groups of children, called "classes." But before we begin to consider teaching the class "science," we should examine the meaning of that special group, the "class." And in this case, specifically the science class.

We place an examination of existing class groupings even before an examination of the objectives of science teaching. We want to discuss objectives in the light of the patterns of "science classes" and "science teachers." We ask then that the reader humor us, and himself, to the extent of reading Chapters 3 and 4 before going on to objectives (Chapter 5) and concept formation (Chapter 6). Then we can look at objectives in the hard light of the situation which exists. We will, in short, examine real classes and real teachers before we examine ideal classes and ideal teachers.

The class

Science classes in high school may vary from enrollments of one to several hundred. Commonly a class consists of a group of students meeting at a certain time in a certain place to study a certain subject. While there is much talk about the "average class size," this is practically a mythical statistic because the teacher rarely meets an average-sized class. He meets anywhere from 1 to 80 children, but usually from 20 to 30. Brown[1] reports that in 1956 the average class size in biology was 28; in chemistry, 23; and in physics, 20. In smaller towns and cities class sizes generally are from 15 to 25, while in large cities they are commonly from 20 to 40.

A class once organized becomes a "captive audience," for the students remain with the same teacher throughout a term or a year. The teacher is a "captive" too. He and this particular group of children have come together because they "elected" *this* subject and had programs with *this* period open. And here they are.

Inasmuch as a teacher does teach a class, and most teachers have five classes daily, what becomes of the individualization of instruction which is considered so important? Is it abandoned? Hardly. Such individualization is to be sought both within the class sessions and after class. Much of what follows in this volume deals with the individualization of learning and of the instruction which induces learning. A teacher is much like the public health officer who is concerned with the health of the community, but knows that the "health of the community" is only a symbol for the total health of the separate individuals.

Here let us consider a class as one group of students among many possible groups. The pupils may be heterogeneously grouped or somewhat homogeneously grouped on some basis. As we consider the different types of classes possible, we shall see how a science program, a pattern of classes and instruction, may be fashioned in a modern school for a modern society.

The organization and personality of classes

A "typical" class. Actually there is no such thing as a "typical" class. Groups of children vary with the community, with the school, with the subject, or with the variety of subjects offered by the school. Nevertheless, when teachers speak of a "typical" class, they mean a heterogeneous group of students varying in intelligence, in sex, in goals, in achievement, and in behavior, but still similar in many ways. Usually they are within a few years of each other in age; generally they come from homes within much the same socioeconomic range; they live in the same community; and, of course, they are

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[1] Kenneth E. Brown, *Offerings and Enrollments in Science and Mathematics in Public High Schools, 1956*, Office of Education Pamphlet 120, U. S. Government Printing Office, Washington, D. C., 1957.

enrolled in the same subject Usually they have much the same scholastic experience behind them Certainly they are distinct personalities, yet they share many common social goals and aspirations; these will be discussed under Developmental Tasks (p. 87). Usually a "typical" class shapes up much like the tenth-grade biology class described in Table 3-1.

Notice the various ranges: I Q scores from 83 to 158, reading scores from 6.5 to 12 0, arithmetic scores from 6 to 12, scholastic averages from 57% to 95%

TABLE 3-1 A typical class

Student	*Age*	*I Q score*	*Reading score*	*Arithmetic score*	*Scholastic average*
1F	14	117	10 4	11 4	75
2F	14	106	9 8	—	70
3F	14	106	8 7	8 3	65
4M	15	109	7 0	10 3	65
5F	14	113	9.2	10 0	85
6M	15	109	10 1	10 6	65
7F	15	141	11.0	11.1	92
8F	11	113	8 6	11.7	77
9F	14	131	10 4	11.1	84
10M	15	106	8 9	10 9	79
11M	14	113	11 0	10 3	95
12F	16	*	7.5 *	9 4 *	65 *
13F	15	105	7 1	10 0	67
14M	15	90	9 7	6.8	60
15F	14	118	11.2	11.5	79
16M	15	109	9 2	11 8	78
17M	15	106	7 6	6 9	75
18F	15	90	7 3	7.7	63
19M	14	121	9 3	11 8	80
20F	15	91	7 3	7 9	83
21F	15	158	11 0	11 8	85
22M	14	90	8 8	8 8	64
23M	14	128	10 1	10 3	85
24M	15	110	9.5	10 9	82
25F	14	106	7.2	7.2	83
26M	14	115	8 0	10.2	90
27F	15	104	6.5	10 6	77
28M	15	139	12 0	11.2	80
29M	15	113	10 8	10 8	76
30F	14	148	12 0	11 8	87
31M	15	111	8 0	9 3	68
32M	15	95	8 5	8.2	62
33F	14	121	8 9	10 0	79
34M	14	83	7.1	5 6	57
35F	14	122	11 8	12 1	91
36F	14	137	11 0	9 4	83

* Recent European immigrant for whom I Q and English reading test scores are not significant. Note the score of 94 on the arithmetic test which required less facility with the English language

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Here they are, and the teacher is expected to interest continually each and every student in the class. He is expected to establish and maintain rapport. Certainly he is expected to have few discipline problems and to deal wisely with those that do occur.

How can these things be done? Many possibilities will be described in the following chapters where we shall develop the nature of experience in science. We shall see that a "heterogeneous" group is actually homogeneous in many significant aspects. Also, we shall discover that a "homogeneous" group is itself markedly heterogeneous. But before we consider the commitment of the teacher to the class and to the individuals within it, let us examine other classes known as "homogeneous groups."

Suppose that by administrative decision we organized groups that were more homogeneous so that they might be encompassed more easily within a teacher's skillful plan and purpose. Suppose we were to organize science classes on the basis of:

Scholastic achievement and promise
Ultimate vocational interests
General, or even momentary, interests

Perhaps we would end up with groups like the following.

A class of science-shy students. Let us focus our attention on five students selected from the class described in Table 3-1.

Student	*Age*	*I.Q. score*	*Reading score*	*Arithmetic score*	*Scholastic average*
9F	14	131	10.4	11.1	81
22M	14	90	8.8	8.8	61
21F	15	159	11.0	11.8	85
7F	15	146	11.0	11.1	92
12F	16	(non English)	(7.5)	(9.4)	(65)

Further work showed that the first three students were science shy and the last two, science prone (see Chapter 8, The Science Shy, and Chapter 9, The Science Prone). The first three were science shy for three different reasons. (There are, of course, many other reasons; this is a very small sample.) The first (9F) was science shy, in spite of high I.Q. and good reading and arithmetic scores, because she was committed elsewhere—to music. Her grades in science varied from 60 to 70; she disliked science and did very little work in it (both cause and result of her dislike); she spent most of her time practicing the piano. Her highest grades were mainly in art, homemaking, and English; she eschewed mathematics.

The second did not do well in science, although he liked it, for he was a slow learner. He was science shy for another reason: understanding science well requires a good mental equipment. He tried hard, however, worked to capacity, and passed the course. (See Chapter 19, Appraising the Student: A General Approach to Evaluation.)

The third student did not do well in science for yet another reason; in fact, she dropped science after the ninth grade. Hers were religious scruples; her parents were almost fanatic in their fundamentalism. Her high school career was marked with difficulties wherever discussions in class (history, English, science) brought up differences in interpretation.

The next two students were science prone. "7F" became very much interested in science, began to do project work, and entered a class in advanced science (mainly individual work). Curiously enough, retesting showed her reading score to be 16 plus and her mathematics score, 12 plus.

And our fifth student, when she overcame her difficulties in understanding English (she spoke German) raised her reading and arithmetic scores to 15 and 12 plus, respectively, and her I.Q. score to 127. She went on to take further science, improving her English progressively; she liked mathematics and made it her life work. She is now working with digital computers.

Our students are science shy for different reasons. But we cannot ignore the fact that most are science shy because they do not have the mental equipment.

If we take the lowest six or seven students from the "typical" class described in Table 3-1 and add to them some 15 to 18 others with similar characteristics, we have a class (Table 3-2) of "slow learners." These are science shy, then, through reasons of mental equipment: they present certain problems in teaching (see Chapter 8, The Science Shy). The group is somewhat homogeneous, for all the pupils are low achievers in academic studies. With them instruction proceeds slowly; remedial work in reading and arithmetic is emphasized, the group is not college bound.

In one school such a class was organized in general science. Table 3-2 shows the basis for selection for this class of the science shy: I.Q. score, reading score, arithmetic score, and scholastic average. Although there is variation between the scores on the various criteria, general agreement is evident. These ninth-grade pupils with low I.Q. scores average about two years below their expected grade level in reading and arithmetic. It is hardly surprising to find that their scholastic averages have been low. They were competing, after all, with all the children who excelled them in ability. Most teachers, confronted with a class such as this, would consider the group practically hopeless. Yet in Chapter 8, Table 8-1 shows the changes in test scores for this same group later in the year after modified teaching procedures (a remedial program), deliberately operated within the interest-arousing context of general science, had been used to help them overcome some of their difficulties. *The test scores show that, given proper opportunity, realistic teaching, and realistic testing, these pupils could and did improve their accomplishments.*

Many science teachers would be troubled at the thought that a science class was the place in which to do basic remedial instruction. ("Science is science and standards have to be met.") Yet what more enticing subject matter than science could be used to involve students to the best of their abilities? While the level of scientific accomplishments was low in this class of science-

TABLE 3-2 *A class of the "science shy"* *

Student	*I.Q. score*	*Reading score*	*Arithmetic score*
1M	81	7.7	4.8
2M	92	6.5	5.8
3F	85	7.3	7.7
4F	83	7.5	9.4
5F	85	7.0	9.4
6M	85	6.9	6.4
7M	72	6.3	4.4
8F	91	7.4	7.7
9M	83	6.8	7.7
10F	79	4.6	
11F	87	8.7	6.4
12M	87	7.2	4.3
13M	101	6.7	9.3
14M	83	5.8	6.8
15F	81	6.9	5.2
16M	83	7.0	9.1
17F	74	7.0	5.0
18F	86	7.1	6.6
19M	80	5.6	7.7
20M	82	6.4	7.7
21M	69	6.5	6.7
22F	87	7.5	7.9
23M	85	7.2	6.0
24F	82	6.1	8.3
25F	75	6.1	6.4
26F	89	7.4	
27F	91	9.4	5.6
28F	87	7.0	7.2
29M	89	5.9	5.8
30F	85	6.8	9.1
31F	75	5.2	6.2

* Average age, 15.5 years; scholastic average, generally 65 and below.

shy students, the gains in the basic skills and in self-respect were considerable. For this group of students, was the loss greater than the gain?

The "special interest" class. Sometimes classes are organized not on the basis of ability or achievement, but on the basis of special interest. For instance, a class in photography, or radio, or auto mechanics may be organized. Since these classes have a content clearly expressed in the title, we would expect those who elect them to be an active, interested audience, and to have had some previous study in science. Such special interest classes are fairly common throughout the country.

The advanced science class. The "advanced science" group is one kind of special interest class. There, the common element is a desire to make science a vocation. Experience at Forest Hills High School, New York (now enrolling 4,500 students), shows that the problems of teaching such a group are different from those in standard courses. Consider Table 3-3, which describes in

TABLE 3-3 An advanced science class

Student	*Age*	*I Q score*	*Reading score*	*Arithmetic score*	*Scholastic average*
1M	14	141		12.0	95.2
2F	14	148	16.6	11.3	97.4
3F	16	122	15.0	12.0	93.2
4M	14	147	13.6	12.0+	91.8
5F	14	131	13.6	12.0	92.6
6M	15	129		12.0+	90.2
7F	15	136	12.3	12.0+	91.2
8F	15	130	14.0	12.0+	90.2
9M	15	138	13.7	12.0+	91.6
10F	15	151	16.6	12.0	98.2
11M	15	131	11.8	12.0	97.8
12M	14	154	16.6+		91.2
13M	15	145	13.4	12.0+	92.6
14F	15	129	16.0	12.0	91.6
15M	16	132	17.0+	10.3	90.6
16M	16	136	13.2	12.0	93.4
17M	15	127	14.2	12.0+	90.6
18M	16	135	15.3	12.0	93.6
19F	15	146	14.4	12.0	91.8
20F	15	143	16.6	12.0	93.4
21F	15	141	16.6	12.0	93.4
22F	15	146	16.6+	12.0+	90.6
23M	16	125	12.3	12.0+	90.0
24M	15	136	13.3	12.0	90.4
25M	16	100	12.5	12.0	90.8
26M	16	132	13.1	12.0+	91.0
27F	15	142	16.0	12.0	95.5
28F	15	133	13.1	12.0+	95.4
29F	16	118	10.9	12.0	94.8
30F	14	155	15.5	12.0	96.0
31F	16	139	13.0	12.0	91.8
32M	15	142	13.9	12.0	92.4
33M	16	127	13.3	8.3 *	93.4
34F	16	139	12.4	12.0	92.4
35F	15	140	13.2	12.0	93.6
36M	16	113	13.0	12.0	91.8
37M	15	131	13.8	12.0	93.4
38M	17	121	10.4	12.0+	94.8

* This arithmetic test score of 8.3 is surprising, on a retest he scored 7.0! Yet in high school this boy did very well in algebra, trigonometry, and calculus. Test scores do not always allow exact predictions of what children can do when given opportunities

part the caliber of the pupils who elected, with guidance, such an advanced science class.[2]

These students are quick learners with high reading scores, high mathematics and I.Q. scores, and high motivation. They must be taught differently from the average or the vocationally uncommitted students (see Chapter

[2] Similar advanced courses are offered in most other subjects. Each child can elect as many of these advanced courses as he wishes and can take his other subjects in "regular" classes.

9). In the advanced science class the students work on small research problems. What they can do is exemplified by a report summary which follows.[3] In such a class where the students try to behave like scientists, attitudes are markedly different, purposes are clear, and energies are well organized. Similar descriptions have been reported from and observed in other schools which provide opportunities for the most promising students to explore through their own "sciencing."

AN ULTRAVIOLET PHOTOSENSITIZATION IN
PARA AMINOBENZOIC ACID AND PANTOTHENIC ACID
FED TO *Tribolium confusum*

I had read that when mice were fed buckwheat and were placed in a strong light they died, while mice lacking either the light, the buckwheat, or both, thrived. Lacking mice, I tried to duplicate the results on insects. I worked with the confused flour beetle, *Tribolium confusum*.

The effect in mice can be duplicated on the flour beetle. I am reasonably certain that:

1. The ultraviolet rays of the light, acting with an agent (or agents) in the buckwheat, seem to cause the reaction known as a photosensitization.

2. When pantothenic or para-aminobenzoic acids (in a concentration of 5 per cent and higher) are added to the diet of the flour beetle, the photosensitizing effect does not occur.

It may be that the photosensitizing reactions are caused by the conversion of either (or both) pantothenic acid or *p*-AB, both of which are needed by the cells to synthesize anti-metabolitic structural analogues. The cells seize upon these structural analogues but cannot utilize them; the cells thus suffer from a deficiency of these vitamins. Death may be the result.

Report. 1,500 words, diagrams

Michael Fried, Senior
Forest Hills High School

"Special classes" after school. Strangely enough, when radio, photography, or electronics is taught during school hours it is called a class and credit is given. But when the group meets after school, it is called a *club* and no credit is given; only pleasure is expected. Throughout the country there are many such voluntary groups meeting as "special interest" units or clubs. Actually they are classes meeting after school hours. Many suggestions for organizing such groups and sources of activities and materials for them are listed in the *Sponsor's Handbook, Science Clubs of America*.[4] Such clubs, to list but a few samples, may be known as: Tropical Fish Club, Engineering Club, Research, Photography, Electronics, Radio, Audio-Visual, Chemists, Biologists, and so forth. Such a club is actually a class homogenized not by I.Q., achievement scores, age, or grade, but by common interest. And there may be only *one* student in such a "class."

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[3] For other examples of research problems and reports see the accompanying volumes: Morholt, Brandwein, and Joseph, *A Sourcebook for the Biological Sciences*, and Joseph Brandwein, and Morholt, *A Sourcebook for the Physical Sciences*.

[4] Science Service, 1719 N. St., N.W., Washington 6, D. C.

The class within its pattern

When you consider all the types of classes—typical, slow, special interest, extracurricular—you can see the rich possibilities in the science program. Indeed the term "class" considered apart from its members and its place in the school program has little meaning.

How a variety of classes and clubs have been fitted together to form a single pattern of science instruction for varied students in one large high school is indicated in Table 3-4. This pattern evolved slowly over a period of ten years under a sympathetic administration which was not afraid to let thoughtful, responsible teachers test out possibilities that seemed promising. This program now fits the varied needs and interests of the children in a large heterogeneous school population

As the pattern of courses in the four track curriculum shown is examined, it will be seen that it is not useful to think of a class, or of a course of study, or of a student in a course of study, unless the course and the student are identified within a pattern. Obviously only schools with enrollments of 2,500 to 3,000 students could offer such a wide pattern of courses; after we examine the significance of each of the tracks shown here, we can consider what varieties of patterning are practical in smaller schools.

Track 2—the normal track. The "normal track," number 2, is comprised of courses in general science, biology, physics, and chemistry. The contents of these courses are what "normally" go by these names. The details of each course are described in Section III, Inventions in Science Courses, Chapters 12 through 15. These courses are of the type generally known as "college preparatory"—a misnomer, as we shall see. As is expected, students successful

TABLE 3-4 *Multi-track science program in a large high school*

Grade 9. One year of general science for all.

Grades 10, 11, 12. Students elect, with guidance, from the four tracks below. (Note that students who elect Track 3 may or may not take Track 4 concurrently.) Students may switch from one track to another at any point. There is also an extracurricular program for all students.

Track 1: For non-mathematically minded students	*Track 2. For majority of students: "normal," with passing mark in algebra*	*Track 3: For mathematically minded students; for those who want to be scientists*	*Track 4: "Advanced science"*
Biology Physical science * Earth science †	Biology Physics Chemistry	Biology honor Physics honor Chemistry honor (Each course is given intense mathematical treatment, as far as the calculus)	Work on independent research problems; teachers available for counseling, can be taken in any or all of the three grades.

* Selected aspects of chemistry and physics encountered in daily life

† Earth science may be elected instead of, or in addition to, physical science.

in these courses are also successful on standardized examinations, both state and private. Students elect these courses for a variety of reasons. Most of them do not consider science as an area of special personal interest or vocational activity. They elect science mainly because a certain number of science courses are required for graduation or for college entrance; or because "everyone takes science" in this school; or because it is not too uninteresting, and it may be interesting; or because it may also be the lesser of all the "evils" among the courses open to them.

In these standard courses students are heterogeneously grouped. Those who do well are usually in the group who will graduate from high school. Generally they will be able to obtain a satisfactory grade (C or better) in algebra.

Track 1. Track 1 consists of courses for youngsters with low reading scores and low arithmetic scores. These are the low achievers, "slow learners," science shy, who are not likely to be college bound. Nevertheless they will vote, pay taxes, defend their country, and play a part in their communities by making decisions involving science in such areas as sanitation, health, civil defense, child raising, school programs, and so on. Their experience with science will also help them live in a world in which science and the fruits of science are increasingly abundant. These students will not be scientists, engineers, or skilled technicians, but they will live in a world of "experts" and should develop some sympathy for the activities and responsibilities of these experts.

Track 3. This is the high-speed road. All courses in it are given full mathematical treatment and often deal, in specific instances, with college level material. The students, in choosing this track, have grouped themselves homogeneously to the extent that they anticipate making scientific work their vocation (or, at least, are interested enough to want to study science in detail). As prerequisites to admission into this program at the tenth grade, students are expected to have had, in the ninth grade, a minimum grade of B (85%) in mathematics, a reading test score of 16.0, and a mathematics test score of 12.0. Table 3-3 shows that some promising children with slightly lower scores may be admitted to test their abilities in this fast-moving class. What is important in such an admission is the child—his determination to live a scholar's life, as well as his test scores. The techniques of teaching such a group are discussed in Chapter 9, The Science Prone. This group is expected to enter college.

Track 4. This track is run concurrently with Track 3, but students in Track 3 are not obliged in addition to choose Track 4. This Track 4 offers a three-year program designed to give promising youngsters an opportunity to do simple "research" in science. As the students have expressed an interest in becoming research scientists, Track 4, known as advanced science, provides them an opportunity to try their wings at real research. On page 65 and in Chapter 9 the type of research such students have done is described.

such schools and spends two full days successively in each school; in each two-day session he assigns work which is then answered when he next rotates to the school.

One small school, like many others, has been able to offer a full program of science courses by alternating teachers and courses in this way:

Teacher A is responsible for the early years of mathematics, and for general science and biology. Teacher B is responsible for the later years of mathematics, chemistry, and physics offered in alternate years.

Both teachers alternate in meeting with a biweekly science club in which the students do independent research and reading. Alternating with this biweekly club is a tutoring session which permits the more competent students to assist those who have asked for aid. Students who must use school buses can be tutored at the lunch period or during a study period.

This brief sketch of varied courses in schools of different sizes shows that the words "biology," "chemistry," "physics," or other course labels have little meaning unless the particular course is seen within the total curricular pattern. For instance, the course titled biology in Track 1, Table 3-4, differs from biology in Track 2, which in turn differs from biology in Tracks 3 and 4. The instruction varies in both substance and manner according to the student population in the classes. To say "class in biology" means little unless the students, purposes, curriculum, and methods of teaching are clearly described.

If the subject matter and procedures differ within courses known as "biology," as well as among biology compared to physics, chemistry, and general science, is there any common denominator among the science courses or any advantage to using the same course labels for classes in different schools, in different towns and cities? What do teachers of these different classes and subjects have in common?

All of these teachers have much in common. Each is concerned that his classes learn considerable scientific information, form concepts, and practice "sciencing" to the best of their ability. The important ingredients which give continuity and coherence to these varied components of the school's science program are:

1. The *processes* (organizing and predicting, sifting and confirming) which are basic to scientific study irrespective of the particular subject material employed or the level of accomplishment attained by individual children.

2. The *product* of these processes, the concepts which give children an idea of the way this world works.

A short excursion into developing one's own pattern in science classes

3-1. What is the pattern of science classes in your own school? If you are not yet teaching, perhaps you can remember the high school you attended, and consider it in the light of these questior

(a) Does it enable all students to take the same courses? Or does it enable homogeneous grouping?

(b) If the latter, is there homogeneous grouping of science shy, or science prone? If not, are the reasons valid?

(c) Are there any special groups like clubs, for instance? How are the special interests of students met?

(d) What is done for the individual (or individuals) who wants to be a scientist?

(e) Is there an opportunity in science for *all* the students in your school?

3-2. What varieties of pattern in science classes exist in your town, city, or state? Have you the courses of study developed by your State Department of Education? These often indicate the pattern of courses found successful in your state. (Also this is valuable information to have if you are a member of a school committee engaged in the determination of successful practices.)

3-3. What "experimental" variation in organization of science classes has occurred in your school (or in the high school you attended) in the past? Sometimes very successful practices are set aside for the moment, and then not resumed. A study of these will help you develop useful tactics and strategy in revising your science class pattern.

3-4. Why not write the Science Specialist, U. S. Office of Education, Department of Health, Education and Welfare, Washington, D. C., for information on recent studies in science? Periodically, the office reviews the pattern of science offerings in the United States. We have listed the most recent report on p. 59 in this chapter.

3-5. Why not write your own university staff or the staff of your own State Department of Education?

3-6. And, of course, if you think we may be of service in helping you organize, revise, or develop a "new" pattern of science classes, or in another way, why not write to us?

CHAPTER 4

Patterns in teaching science:

Science teachers

A note at the beginning: Ah, the good old days. Claude Coleman gives us one reminder[1] of some of these "good old days." He records the account of a "teacher" who had taught for fifty-one years; during this tenure his services included "911,527 blows with a cane; 124,010 with a rod; 20,989 with a ruler; 136,715 with the hand; 10,295 over the mouth; 7,905 boxes on the ear; 1,115,800 slaps on the head . . ." One can guess at this "teacher's" pattern.

Teaching is a personal invention and every teacher has his own pattern. But there are different kinds of inventions and patterns. In this chapter we are concerned with three general types, each with a distinctive flavor. These center around three identifiable approaches in the process of teaching.

Three patterns

As one observes teaching throughout the country (and we have observed hundreds of excellent teachers, and unfortunately many poor ones), one is forced to look at the teaching process in the public school in historical, perhaps even evolutionary, perspective. An observer becomes conscious that perhaps schools, and the teaching processes practiced in them, exhibit an evolutionary sequence and that different schools are at different stages of evolutionary development.

We see the teaching process developing toward a recognizable goal: the introduction into school and classroom of methods and procedures which are the applied results of half a century of research in the psychology of learning. Where teaching procedures of an individual teacher or school ignore what has been learned from research and observations on effective teaching, the more

[1] Claude Coleman, "The Hickory Stick," *Bulletin, American Association of University Professors,* 39, 457, 1953.

primitive stage of the evolutionary process toward effective teaching exists The direction of this process is *from* authoritarian teaching, with the objective of transmitting the knowledges, skills, and attitudes derived from a traditional subject-matter oriented curriculum in which success is measured in terms of grades, *toward* a type of teaching which is the cause, as well as the result, of mature planning among teachers, children, parents, and administrators in a continuous attempt to improve teaching and learning. In the latter case the curriculum is planned cooperatively by teachers and supervisors, sometimes with parental assistance, units and lessons are planned cooperatively by teachers and students. Growth of teachers and students, and of the community, is the objective. One thing must be made clear: at least as much subject matter is learned with the latter approach, when it is practiced with skill. (See pages 78-82 for testimony, if not evidence.) This approach begins with the needs and interests of all concerned (students, teachers, and the members of the community) in the learning process, whereas the former considers a temporary recollection of facts as the major hallmark of educated men and women.

A caution and a generalization: We presently know of no one way of teaching, no one curriculum, no one philosophy which fits all classroom situations, all communities, all subject areas, all teachers. Research to date yields no one method applicable to the teaching scene generally. Teaching is essentially an art based upon the psychological results available. Above all else, the teacher is a responsible human being in a situation rife with human aspiration.

A pattern of domination (Mr. A.)

Mr. A. was considered a good teacher of chemistry in the school where he taught His students generally scored well on the state's standard examination, in fact, they were among the highest scorers. He rarely had discipline problems Although he never volunteered, or undertook on his initiative, the supervision of a science club, no one really minded, because "he did his job." And in the large high school where he taught chemistry there were others who took on the extracurricular activities.

When he spoke at faculty meetings, he would sometimes say, "Unless you give daily homework, you can't expect results. These students don't work the way we did."

And in department meetings, when problems of discipline were discussed, he would say, "I never have any trouble; my students do exactly as I tell them"

As a matter of fact they did. One day when Mr. A. was absent another teacher tried to teach the class. He manipulated a problem in chemistry (weight-weight) in such a way that the students could not use the approach they had been taught by Mr. A. In effect the students told the teacher, "Mr.

A. never taught it to us this way. He wants us to do the problems in these steps. We are marked off if we don't do them his way." [2]

What these students were saying was, in essence, that they were becoming set in their ways of solving chemistry problems. They were being forced to follow one routine, which was presented to them ready-made. Instead of thinking through each new situation, they expected it to be like the last standard example (and it was; Mr. A. saw to that), and reacted to it in the same way. This is "stimulus-response" psychology carried to a ridiculous extreme. By demanding the practice of his routine, clever as it may have been, Mr. A. was *reducing* readiness to think, *reducing* readiness to reason. His students were discouraged, even prohibited from attempting to seek concepts through creative problem solving.

These were students carefully being "prepared" for college entrance examinations. The reports from far too many college teachers are that such students were hardly being "prepared" for collegiate study. Otherwise, why would so many collegiate instructors assert that they would rather (yes, *rather!*) have students who had not studied the subject, say chemistry, in high school? This is a devastating remark to make. It is almost the maximum insult to high school teachers; for have they not spent their lives "preparing" students for these very college courses? Surely something is basically wrong.

In an effort to explore this serious assertion, one of us has proposed a hypothesis which many of the critical college teachers say is essentially what they observe and what provokes their unkind remarks. It runs like this:

The entering college freshman believes he knows something about a subject because he has "had" a course in it. Actually he has a speaking acquaintanceship with some information and a recall of some generalizations. However, this exposure has covered too many separate topics; it is woefully "thin" everywhere. The student does not know how any of the generalizations were developed; he does not know where they apply; and, more serious, he does not know where they do *not* apply. He is very proud to write "H_2O" in place of "water" and never knows that H_2O, the real pure chemiral, is a rarity even in collegiate laboratories. He knows that $PV = k$, but he does not know that this is a theoretical notion applying only to an "ideal gas" and only when the temperature is held constant. He does not know that most gases will condense to a liquid when the pressure is raised to a few hundred atmospheres. He has not *solved* problems; he has only *done* them. He has not attained, or formed, concepts; he usually repeats what he has memorized. Later, in college, he is obliged to "unlearn" or "relearn" what he proudly believes he knows, before a more analytical and realistic study of the subject can be presented, that is, before he truly attains the concept. He is too ignorant to realize how

[2] This remark always reminds us of two very interesting studies: A. S. Luchins, *Mechanization of Problem Solving—The Effect of Einstellung*, Psychological Monographs, Vol. 54, No. 248, 1942, and Hy. M. Schroder and J. B. Rotter, "Rigidity as Learned Behavior," *Journal of Experimental Psychology*, *44*, Sept. 1952, p. 141.

primitive stage of the evolutionary process toward effective teaching exists. The direction of this process is *from* authoritarian teaching, with the objective of transmitting the knowledges, skills, and attitudes derived from a traditional subject-matter oriented curriculum in which success is measured in terms of grades, *toward* a type of teaching which is the cause, as well as the result, of mature planning among teachers, children, parents, and administrators in a continuous attempt to improve teaching and learning. In the latter case the curriculum is planned cooperatively by teachers and supervisors, sometimes with parental assistance, units and lessons are planned cooperatively by teachers and students Growth of teachers and students, and of the community, is the objective. One thing must be made clear: at least as much subject matter is learned with the latter approach, when it is practiced with skill. (See pages 78 82 for testimony, if not evidence.) This approach begins with the needs and interests of all concerned (students, teachers, and the members of the community) in the learning process, whereas the former considers a temporary recollection of facts as the major hallmark of educated men and women.

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of each laboratory period (held once a week) to be certain the students knew how to set up the equipment and what results to expect. Furthermore, Mr. A. introduced each topic, e.g., Oxygen, Solutions, Hydrochloric Acid, Halogens, Bases, Earth Metals, etc., with a lecture-demonstration.

Students had little to complain about. They had elected chemistry. They were taught chemistry. If they did their work, they "passed"; if they didn't, they "failed." Grades were given as a strict mathematical average on the basis of Mr. A.'s tests. Mr. A.'s students always did well in the examinations which the school gave. They did not generally gather about him after class, or after the course was over. They were polite to him, however, and he was polite to them.

They learned chemistry; he taught chemistry.

To the reader: Turn now to the list of characteristics in the teaching process on page 84. Check those factors which characterize Mr. A.'s approach. Or, if you wish, wait until you have examined the patterns of Mr. M. and Mr. P.

A pattern of the laissez-faire (Mr. M.)

Mr. M. was quite young. As a student he had become dissatisfied with the rigid patterns of the teachers in a "college-oriented" school he had attended. As he used to tell it:

> What they did was as predictable as the rising and setting of the sun. A lecture was given for 30 minutes, then, questions were asked for 20 minutes on the previous day's work. Everyone knew what the lecture was to be; it followed the text and references (college freshman texts) pretty much.
>
> The questions were predictable, they covered the readings assigned. If you memorized fairly well, you were certain of a good grade. If you didn't recite well, the instructor usually reminded you that you wouldn't do well on the College Board Examinations. I was bored, and so were most of the other students.

As a student teacher, Mr. M. had observed not only a high school teacher in science, but an elementary school teacher as well. He observed how the latter apparently let children do much as they pleased, yet they seemed to learn very well. (He wasn't experienced enough, as we shall see, to note that she *knew* the children very well and *planned* very carefully.)

He had read widely and was much impressed by what he considered progressive education: to wit, emphasis on the growth of children, not primarily on subject matter. He determined to try a version of his own in science; and he *did so, in general science.*[3] *He determined, in short, to let children plan* the course pretty much on their own. He determined to exert very little control. After all, he thought, there were no College Boards in general science.

The result was not what he had expected.

He began (the very first time he met them) by asking his students enrolled in ninth grade science, "What do you want to do this term?" He impressed on

[3] In a Midwestern city school, population 2,100 students.

little he knows. He has been trained to jump through a certain set of hoops, but unfortunately in the real world, and even in college, jumping through these particular hoops is not considered especially important.

The tragedy here is that Mr. A. and his many colleagues thought that they were "doing their job," but they never tried to analyze what "their job" was. They have the knowledge, the intelligence, and the inherent abilities to bring children to self-controlled learning, but this never seemed important to them.

Mr. A. would never have thought of it this way; he would have rejected any suggestion that he wasn't teaching students how to reason. In fact, he believed that hard work in learning resulted in improved thinking—the harder the better. Mr. A. believed firmly that science develops logical thought. He was not interested in the fact that, more than a quarter of a century ago, the appealing assumptions of faculty psychology had been discredited experimentally. In fact, he used to say that psychology was not a science but "quackery." What he had to say about *educational* psychology would not bear repeating.

Mr. A. operated on schedules. His work was laid out carefully in a complete schedule posted on the bulletin board. He covered the entire course of study; he did not tarry for the slow nor hurry for the fast. When, year after year, the slow fell far behind, they were admonished to "work harder." The abler students were admonished to "work for perfection"; to memorize and memorize until they knew 100% of 100% of the course. Enrichment and acceleration, Mr. A. maintained, could wait for college, which was the place for it anyway.

And the exams! Every three days, a short ten minute quiz; every week (Friday), a full period quiz. Every four weeks, a monthly quiz. The quizzes were mainly of the short answer form with many problems and were always concerned with chemical details:

"Describe the Solvay process using equations only."
"Balance the following ten equations."
"What volume of bromine will be prepared if 200 grams of sodium bromide are used?"

And the entire problem was wrong if it wasn't done to two decimal places.

If one visited Mr. A. when he was not conducting a quiz, one could see the students at work. Yesterday's lesson had ended with an assignment, usually of this sort:

"For tomorrow, Chapter 21. Do all the questions and problems."

Next day for twenty minutes, students were sent to the board to answer the questions and problems. For a few minutes Mr. A. answered questions about the chapter. When he found, through the questions students failed to answer, that they did not understand a chemical process, he gave a brief lecture-demonstration. In addition, demonstrations were done at the beginning

We want to take pictures. Can you get us film? We'll bring the camera. (Mr. M. did break the red tape to get a special budget for his class.)

As the work went on, Mr. M. began to see things he wouldn't have accepted until he had tried his way; some he noted to his dismay, some to his elation, while others just baffled him. What he saw, or consciously recognized, he stated in the report he made to his chairman. Here is a partial list excerpted from that report:

Some good things happened.

a I really think the kids learned to work together (although I really can't know whether that was the result of the method I used—no experimental control).

b The best students learned a good deal. When reports were made they listened carefully, they asked questions, they read further. So they did pretty well on the exams. The exams were fair; I saw to it that they covered the work done rather well.

c The kids learned to report, even some dull ones talked up.

d. I really believe some of the best were stimulated to go on to science because they had a good deal of freedom.

Most things, I would say, were negative or indifferently poor:

a. A few kids took over, in each committee there was usually one.

b. Not all kids worked equally hard, about one third of the class loafed.

c. After three weeks of work this way most kids were pretty bored.

d. When they gave reports (after three weeks of activity, the first group on "Astronomy" gave an encyclopedic report running for ten days) most kids were pretty boring; they read their reports, used few visual aids, and didn't speak up. In short, they just weren't teachers. I don't know why I expected them to be.

e. The poorest students were just left out.

f. In reporting (and in their work generally) most of the kids didn't know what weight to give important or unimportant aspects of their work. They slighted principles and emphasized details; they used vocabularies of unnecessary difficulty; they didn't use the board; etc.

g Worst of all I began to worry that they had left out some pretty important topics. (What of next term?) They hadn't selected "Photosynthesis," for instance; they had missed "Lighting at Home," "Fire Extinguishers," etc.

So in the middle of the term, when a particularly bad two days (very boring) had just gone by, when Joan asked worriedly, "How are we going to do in our next year's work, Mr. M.? All my other friends are taking different topics from those we are," I suddenly took the bull by the horns and asked, "How would you like me to take over for the rest of the term?"

I still remember the look of bright relief on the faces of almost all the youngsters. The few who weren't relieved were probably wondering why I hadn't done this in the first place.

Mr. M. would have saved himself considerable anxiety if he had read the famous study of K. Lewin, R. Lippitt, and R. K. White, "Patterns of Aggressive Behavior in Experimentally Created Social Climates."[4] This study is also reported with photography in Goodwin Watson, "What Are the Effects of a Democratic Atmosphere on Children?"[5] There are many other related studies

[4] *Journal of Social Psychology*, *10*, 271, 1939.

[5] *Progressive Education*, *17*, 336, 1940.

them that: they could do what they wanted, he was there only to help them; they could work in groups, individually, or as a class; the examinations were to be made up by the students (with his guidance).

The class was gratified. The students were of middle-class homes and well behaved; besides Mr. M. was personable and had a "way" with students.

A class chairman was appointed pro tempore and the students fell to suggesting topics for study. Within a few days they had the following list on the board—each topic ably defended by its protagonists.

Psychology	Why do we behave as we do
Botany	Animals
Chemistry	The Microscope
Astronomy	Television
Bacteria and Disease	Airplanes
Satellites	Electricity
Evolution	Life on Mars
Nuclear Energy	The Human Body
Antibiotics	Reproduction
Fish	Farming
	Pets

As Mr. M. tells it:

> I thought, even if this were hodgepodge, it still indicated their interests, possibly even their needs. Soon, however, I wasn't so sure; I began to suspect that some of them were suggesting topics just to get attention; some of them to please me; and some just for the heck of it.
>
> Nevertheless, I was going to see it through. Besides, my department chairman said, "Go ahead, let's see what happens."

The chairman of the department suspected what would happen, but he also knew that Mr. M. had great promise and would learn from whatever happened. So he left Mr. M. on his own to a great extent, although he was ready to help if any real "discipline trouble" arose.

There were sensible students in the group. They saw that several of the topics really belonged together and they argued this well. (Thus "Antibiotics" was placed under "Bacteria and Disease"; "Life on Mars," under "Astronomy"; etc.) After discussing a few "Rules of Getting Along and Getting Work Done," the group divided itself into committees (except for the boy who wanted to work on "Fish") and began to work.

Each day, the groups met, working in allotted corners and other spaces of the room, and in the library when necessary. Mr. M. sat at his desk ready to help. And students, appointed as group chairmen or self appointed, did come up, asking such questions as:

What books can we get on glands?
How can we get Ralph to work? He just sits around.
When can we report to the class?
How do you want us to write this up?

to put these into practice in his classroom. He proceeded to do so. Let us say at the outset that his students did very well in the examinations; they even elected more science in later grades; more than that, a number far in excess of that expected took to science as a career; and more than that, a good number took to Mr. P. as a father-surrogate.

When he met his class, Mr. P. began by asking, "If you could have planned this course, what would you have included in it? Or, to put it another way, what would you really like to know? What would you like to learn?"

In the discussion which followed several things happened, most of them predictable

1. Some students began suggesting topics such as these, which were put on the board:

Why do we behave the way we do?
Why are we like our parents? Why aren't we?
Life in the past.

2. Other students began suggesting topics such as these, also put on the board:

Botany
Zoology
Digestion
Anatomy
Nutrition

3. Still others, cautious, even prudent, asked, "Don't we have to take the state examination?" To which the answer was an unequivocal "yes." Then: "Shouldn't we take the topics which will prepare us for that examination?" (And some added, "For the College Boards as well.") To this also the answer was an unequivocal "yes."

The questions and discussion were resolved into a pattern which might be stated like this: "What can we do this year which will accomplish three purposes:

1. To study those topics which will help us live better lives; things we need to know.

2. To study those topics which will help us do our best in the required examinations.

3. To study those topics which are interesting (hobbies, projects, etc.). These may even be individual topics such as 'Cancer in the Swordtail' (a project done at home)."

During the next week each topic was discussed by the entire class (and we mean discussed!). Its advantages and disadvantages were weighed in the light of the amount of class time available, its priority in helping improve the quality of living, its usefulness in helping pass examinations (state and College Board), its special interest to a few students.

available.[6] Perhaps even more valuable would have been a thoughtful reading of any modern text on teaching methods.[7]

To the reader: Now Mr. M.'s experience is noteworthy and very much like the experience of "Mr. Osborne" as reported by Cronbach.[8] If you do study Mr. Osborne's experience, you may want to check that account, as well as our Mr. M. against our list of statements underlying class management in science, in the "Excursion" at the end of this chapter.

It would be fine if we could say that Mr. M. developed his teaching pattern into one in which coordination and planning became part of his teaching approach. Mr. M., however, did not get the best possible help from his supervisor or from administrators, who apparently wanted a pattern like Mr. A.'s, but believed in a "sink or swim" approach to teachers. Mr. M. left teaching

A pattern of the democratically planned (Mr. P.)

If Mr. M. had had appropriate help from his supervisor and had had additional training, he might have developed the pattern of Mr. P. Mr. P. had oscillated between a pattern of domination and one of laissez-faire; neither satisfied him. The latter did not leave room for the kind of responsible guidance he thought a teacher should give his students; the former did not encourage personal responsibility and growth in goal forming and concept seeking, which he believed should be a pars of every person's education.

What was Mr. P.'s approach to teaching?

He taught in a school with a normal population, that is, a population diversified in I.Q., reading score, and socio economic background. The students were expected to take a standard state examination; most of the college bound would probably take, in addition, the College Board Examination. The school was also expected to show up well in these examinations

Most teachers in the school thought the best way to help students achieve success in these examinations was to teach the way our Mr. A. did—with kindness, of course. (The only trouble they could find with our Mr. A.'s method was that he pushed too hard, he was too tough; a bit of kindness would have helped Mr. A., they thought; yet, after all, "he did his job.")

Mr P. did not believe this at all, he knew that there had been advances in the psychology of approaching class management and learning; he wanted

[6] For example, H J Bingham, "The Relation of Certain Social Attitudes to School Environment," *Journal of Experimental Education, 9*, 187, 1940
R B. Embree, Jr., "Children Compare Two Types of Education Experience," *School and Society, 50*, 319, 1939
L. T. Hopkins, "Seniors Survey the High School," *Teachers College Record, 42*, 116, Columbia U., 1940

[7] W H. Burton, *The Guidance of Learning Activities*, 2nd ed., Appleton Century Crofts, N. Y., 1952
B Othanel Smith *et al.*, *Fundamentals of Curriculum Development*, rev. ed., World Book, N. Y., 1957.

[8] L. J Cronbach, *Educational Psychology*, Harcourt, Brace, N. Y., 1954, pp 442 46.

and which fed back results when reports were made or questions raised. That is, individual expertness was encouraged and recognized. Mr. P. was available to advise on these projects, to redirect efforts that were stalled, or to expand, through questions, efforts that seemed to have run dry.

Mr. P. had by this time convinced the class that they and he, together, could plan the course successfully. He remembered that only his first few classes had floundered; he had learned to trust his students. One of the things he had learned was that the success of the work depended on class committees and time given for planning. And there was the rub. There was never enough time.

Finally he had hit on this plan.

He met once a week with the committee chairmen who formed the Executive Committee. One week the meeting was early in the morning (before school); another week it was in the afternoon. Here ways of proceeding were ironed out. Here reports, directions, laboratory work, films, field trips, lessons in which Mr. P. took the lead, were planned and scheduled. The committee also examined the three available texts and selected one for major use. In this way Mr. P. met with committees in all his classes.

Each chairman scheduled meetings with his own group out of class: at home, during study periods, during lunch period, etc. In any emergency, the committee could call on Mr. P. Somehow he managed to arrange meetings. (The reader will see that Mr. P. believed in extracurricular work.)

Each committee assigned one person to the class laboratory squad. This laboratory squad planned the materials necessary, ordered them from the science department's laboratory squad,* and saw to the distribution of the materials, their collection, and their return. (The department laboratory squad also saw to the preparation of materials and their maintenance and repair.)

What was Mr. P.'s part in the day-to-day work? It was that of a teacher whose concept of science was described in Section I. Hence, he believed in permitting students to do their "damnedest with their minds, no holds barred." The reader will have noted that the course the students planned included *more* subject matter, not *less*, than would be found in a course within the pattern of teacher-domination. This is generally the result of a teaching approach which permits the students to help in the formulation of goals and objectives. The morale of the class, the motivation of the students, is high when the purposes of learning are clear and acceptable to them. These students worked very hard.

Mr. P. taught often; planning by students doesn't mean abdication by the teacher. When he found that a student's report needed clarification, he asked questions which illuminated. When he thought that a topic was not fully covered, he made suggestions. When the topic was too difficult to be handled by a student, or group of students, he became a member of the committee and planned with them; he taught actively, usually in the pattern of questioning.

He was a guide and friend; he was firm and demanding, but not coercive;

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* A discussion of student squads may be found in the companion volumes: Morholt, Brandwein, and Joseph, *A Sourcebook for the Biological Sciences*, and Joseph, Brandwein, and Morholt, *A Sourcebook for the Physical Sciences*.

We have watched such classes at work, and the students are clearly sensible. They even admonish each other on wasting time in repetitious discussion.

At the end of a week or ten days, a list of topics and their subdivisions, as developed by a committee of students interested in a special topic, was placed before the class. The topics were in three categories usually. And Mr. P. attests to the fact that free discussion and skillful questioning almost always result in these three categories. (Mr P uses the pattern of teaching described in Chapter 7 always questioning, refraining from giving information.)

Category A. Topics we should like to discuss in class. (Includes activities we should like to do in class)

1. How our bodies work (anatomy, physiology; includes dissection of frog, rat, cell studies).
2. Why we behave as we do (elementary psychology).
3. What we inherit (heredity, reproduction).
4. Our origins (evolution, also such activities as a survey of animal and plant kingdoms to show evolutionary relationships; includes field trips).

Category B Topics we can read for ourselves Permit one class period every week for questions (planned by a committee with teacher's advice; see p. 81)

1. Plants and animals (classification).
2. Conservation (to be reviewed when field trips are conducted).
3. Nutrition (to be reviewed when physiology is discussed).

Category C Individual and group projects and readings. (To be done at home or during free periods)

1. Preparing permanent microscope slides.
2. Raising tropical fish.
3. The embryology of the snail.
4. Culturing protozoa.
5. Studying heredity of the characteristic "dimpling."

With three different categories of topics to be considered, Mr. P. and the class agreed upon a working procedure. Topics in Category A were taken up sequentially in class, each being considered for some weeks or even months Each topic was subdivided into four or five smaller components on which committees worked with the constant advice and encouragement of Mr. P. Thus the whole class was at one time working on the same general area, yet there was opportunity for individual special interests.

Topics in Category B were, as mentioned, read from standard texts and other references outside the class, but one period each week was reserved for questions. The scheduling of the reading and discussion was planned by a student committee, who knew that they would be taking the required examinations.

Category C involved aspects which usually grew out of Category A or B

TABLE 4-1 Some consequences of three teaching patterns *

	Undirected	*Group control*	*Teacher control*
Pattern	Uncoordinated	Coordinated	Dominated
Teacher's role	Vague adviser	Mature, wise group leader	Task-setter, drill-master
Emphasis	Momentary interests of individual pupils. "fun"	Significant group problems developed to fullest extent possible with maturity of pupils	Recall and recognition of academic subject matter, practice of academic skills
Direction	Unguided, uncritical	Self-responsibility, learning how to learn	Success on examinations, collegiate admissions
Emotional security	Disturbing because of low accomplishment of vague tasks	May be frustrated unless group plans clearly	Relieves anxiety by set standards, if clearly stated; teacher assumes responsibility
Enjoyment	Enjoyable until anxiety appears	Enjoyable if group sees progress toward clearer goals	Individual enjoyment from compliance to set tasks, but not enjoyed by all
Effort and efficiency	Low persistence, wasteful	Self-directed toward chosen goals, continuous when leader is absent	Effective if group accepts direction of effort and leadership of teacher, otherwise resistance and minimal response
Study patterns	Haphazard	Often intensive, self-initiated toward clear goals	Highly organized by teacher, little pupil initiative
Assignments	Few, vague	Group planned	Set by teacher
Learning of course materials	Not much evidence, probably quite ineffective	As good as teacher controlled classes, possibly superior for altering attitudes, approach emphasizes process of scientific inquiry	Averages as good as group-controlled classes on academic recall and application
Evaluation	Testing difficult, too diverse activities, some appraisal of individual efforts	Tests involving novel problems-situations; continual observation, reports	Major reliance on tests, both standardized and home made
Type of student favored	Self reliant, previously motivated	Equal opportunity and encouragement for science shy, typical, and science prone	Academically inclined, conforming, college-bound

* Based in part on L. J. Cronbach, *Educational Psychology*, Harcourt, Brace, N. Y., 1954, esp. p. 459, and W. H. Burton, *The Guidance of Learning Activities*, 2nd ed., Appleton Century-Crofts, N. Y., 1952, after lengthy discussion, esp. pp. 325-27.

he was permissive. There was an absence of threat in his class; there was freedom to proceed with the business of learning, not freedom to disrupt learning. Is it strange that Mr P. had few discipline problems? The students and he, as teacher, were engaged in a commonly accepted, commonly planned activity.

What of the poorer student—the science-shy student? Actually he had a *much better opportunity* in Mr. P.'s class than in Mr. A.'s or Mr. M.'s. In Mr A.'s, he would have failed. In Mr M.'s, he might not have failed, but he could have gotten by with doing very little He might even have become a first-class nuisance. In Mr. P.'s class the other students expected him to contribute in committee work, he prepared a report, and he reviewed in committee and in class Since he had a stake in planning the work, there was greater likelihood that he would work to capacity In fact, Mr. P.'s classes were known for their healthy learning atmosphere, there were *few, if any, discipline problems*

What of the science-prone student? Clearly he had an opportunity to exert leadership; clearly he could extend his learning beyond normal expectations; clearly he could work in a group or work individually. No limitations were placed on him; *individuality* was not crushed, but encouraged. In fact, Mr P.'s approach depends on enlisting the leadership of the science prone student.

In short, Mr. P. had developed an approach which enabled him to meet the needs and interests of different individuals within a class. This he did by adapting to the situation in class the principles of learning, gleaned from recent investigations of the conditions most fruitful for group learning.

Furthermore, we know that Mr. P.'s students did as well in the state examinations and College Boards as did *other students* in his school taught by the lecture method.

And Mr. P. was one of the most, if not the most, respected teacher in the school, one of those most liked by parents and students, and clearly appreciated by his colleagues and the administration. His colleagues called him a "teacher's teacher."

An excursion into appraising the teacher as classroom leader

Our readers will no doubt have put themselves in the places of our Mr. A., Mr. M., and Mr. P. This would be, at least in part, a snare. For we insist that, an individual's origins and development being what they are, teaching approaches remain personal inventions. Nevertheless, there are frames of reference; and those of us who respect excellence aspire to it.

To repeat, the three "types" we have described, all actual cases, fit into the prototypes, as they emanated from the famous study of Lewin, Lippitt, and White.[10] With regard to the development of the science-prone student, or

[10] *Op cit*, p 77.

13. Some science teachers believe that adolescents do not know what they want or can do, and must be told.

14. Some science teachers, in their teaching, really satisfy their own needs (for security, status, recognition) rather than those of their students.

15. Some science teachers, in their teaching, attempt to satisfy their students' needs.

Of course, it will be said, and rightly, that these statements apply to all teachers, not to science teachers only. But the success of the science teacher is not measured only by his success in teaching science per se; we repeat, he teaches science *to students*. Hence the nature of his attitudes and approaches to his class, and his management of its students ace of paramount importance.

The success of the science teacher in teaching science cannot be greater than his success in managing his science class.

the "scientifically gifted," Brandwein[11] found that a situation which favored the "democratic planning" approach in the science class was more fruitful in developing these students than either the "authoritarian" or the "laissez-faire" approach. This is in accord with the findings of Lewin, Lippitt, and White, and others. Furthermore observations throughout the country indicate quite clearly, almost beyond the shadow of a doubt, that in the general estimates of students, supervisors, administrators, and the community, the teachers whose approach to the classroom is centered around "democratic planning" are considered to be most effective Sometimes the oft used phrase "democratic" seems to lose its central meaning a system of checks and balances to avoid both the domination of an absolute monarch (Mr. A.?) and the chaos of anarchy (Mr M ?)

4-1. Where do you place yourself? Where do you place Mr. A., Mr. M., Mr. P., and other teachers you have known, on Table 4-1?

4-2. In your estimation which of the statements below apply most characteristically to Mr. A.'s teaching pattern? Mr M.'s? Mr. P.'s? To your own—present or planned? Or do they not apply at all?

1. Some science teachers drive, even bully, their students to work.

2. Some science teachers have classes which come in ready to start work and to enjoy it.

3. Some science teachers are humorous and friendly, albeit firm and helpful.

4. Some science teachers are in almost continual conflict with their classes

5. In some science classes keeping quiet is safer than volunteering an idea that may be rejected

6. In some science classes admitting one's difficulties to the class results in friendly and fruitful help.

7. Some science teachers believe that pupils will not voluntarily engage in useful work.

8. Some science teachers believe that students will engage in fruitful work, especially if they take a useful part in planning the work and in working toward an acceptable goal.

9. Some science teachers believe that students can be left to their own devices, and can thereby achieve worthwhile learning.

10. Some science teachers believe that subject matter is something to be "covered" before going on to something else.

11. Some science teachers believe that classwork is part of the general goal of teaching—helping students to improve the quality of their lives by directing their work toward enduring purposes and processes.

12. Some science teachers believe that since group control is the usual pattern in adult life, it should be increasingly used in class management.

[11] Paul F. Brandwein, *The Gifted Student As Future Scientist*, Harcourt, Brace, N. Y., 1955, p. 51.

Bases for a statement of objectives

A base in developmental tasks

One set of these aims and objectives is based on investigations in the growth and goal building of children, and must thus be based upon an understanding of what children need to learn in order to lead successful lives. For, after all, while teachers are all proprietors of the *teaching process*, the student is the sole proprietor of the *learning process*.

Increasingly teachers have realized that they must consider the inherent interests and capabilities of the learner, as well as the subject matter; the *who* as well as the *what* of learning. Certainly a carpenter working with pine wood does not treat it as he would oak, no matter what he is attempting to build. Psychological studies, still in their infancy, have already shown the importance which internal motivation and goal building have on learning. In the field of sports there have been a number of international champions who were stricken with polio or other severe disabilities, and who probably became champions because of their drive to overcome the affliction. Constantly haunting all teachers is their awareness of the potential achiever who lacked drive and wasted his talents. Although the teacher is not the only one who shares responsibility in such cases, his conscience still bothers him, for he might have held the key and not known it.

Effective teaching is based upon a clearer understanding of the "developmental tasks" of children. According to Havighurst,[1] elaborating on an idea of Corey, these developmental tasks are simply the things that children *must* learn in order to live satisfying lives. (Note that this satisfaction is in the learner, not in some external judging board.) Havighurst used this definition:

> The developmental task concept occupies middle ground between the opposing theories of education: the theory of freedom—that the child will develop best if left as free as possible, and the theory of constraint—that the child must learn to become a worthy responsible adult through restraints imposed by his society. A developmental task is midway between an individual need and a societal demand. It partakes of the nature of both. Accordingly it is a useful concept for students who would relate human behavior to the problems of education—without, I hope, obscuring important issues in educational theory.
>
> The tasks which the individual must learn—the *developmental tasks* of life—are those things which constitute healthy and satisfactory growth in our society. They are the things a person must learn if he is to be judged and to judge himself to be a reasonably happy and successful person. A developmental task is a task which arises at or about a certain period in the life of the individual, successful achievement of which leads to his happiness and to success with later tasks, while failure leads to unhappiness in the individual, disapproval by the society and difficulty with later tasks.

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[1] Robert J. Havighurst, *Developmental Tasks and Education*, Longmans, Green, N. Y., 1950, pp. 4, 6.
See also, Stephen M. Corey, *The American High School*, ed. by H. L. Caswell, Harper, N. Y., 1946, Chapter 5.

the science classroom? They are in the tradition of science. Who is better equipped to interpret the results of scientific investigations in learning (or teaching) than the science teacher? He is, also, part and parcel of the scientific tradition. He is *in science*.

Nevertheless, the developmental tasks we have dealt with briefly, or the modern aspects of psychology, are certainly not the only source of objectives.

A base in field covering

Some science teachers still seek their objectives in subject matter. To them the study of subject matter is the means through which boys and girls become responsible adult members of society. While this proposition is partially correct, it is incomplete because it neglects the student's internal motivation to learn.

Most teachers practice what can be called the "field-covering" approach. They accept the total dictate of a subject matter field and its appurtenances, content as outlined by textbooks, examinations, and tradition. Teachers who try to "cover the field" are faced with eternal frustration; the field is too large to be "covered." Their basic aim is then to cover *enough* of the field so that it is *introductory to covering more of the field*. Elementary chemistry "covers" chemistry, but only preparatory to "covering" college chemistry, which is in turn often introductory to the field. In practice, then, "covering" the field merely means *sampling* it. The basic question then becomes whether or not the previous or traditional samples are necessarily the most effective for all teachers, all objectives, and all students.

What criteria, what aims and large objectives of teaching and learning does a teacher use to select the materials which are his sample? Selection of a sample becomes increasingly more difficult as the years go on, for in science the fund of information and concepts are constantly increasing. Generally selection is simplified, and vigorously defended on the basis that the material to be covered is:

1. Dictated by a course of study (developed by curriculum experts or a committee of teachers acting as experts).
2. Dictated by a textbook (developed by authors and editors who are wiser than the individual teacher).
3. Required for an examination to be taken (standard achievement examinations, state examination, or College Entrance Examination).
4. Required for college entrance.
5. A duplication of a college course taken by the teacher.

In the privacy of your own thoughts, examine each of the five bases listed above. To what extent is each supported by factual evidence, in contrast to hearsay and the mythology of education? In what ways do these contentions fit with the teacher's responsibility to help children grow in wisdom? In making this assessment you might wish to note in two columns the arguments and

ously stated and are to be found in textbooks. Conversely, some objectives are so heavily framed in terms of "doing" or activity, that is, the *external, observable* aspect of learning, that the intellectual basis is disregarded. *Both internal (mental) and external (observable) must be attained* and *both must be stated explicitly*. Generalizations without experience and new applications are essentially verbalisms, of which we see too many. Frantic activity for the sake of "doing something" frequently degenerates into vague "messing around" without purpose or significance. Both learning and doing go together and should be planned that way. While the teacher's interest may center in the intellectual (invisible), the student's interest may center, and usually does, in the activities—what he can do. *Effective teaching blends the two.* The concepts sought in an attempt to improve the quality of life and living have significance to the learner mainly as they are applied to an understanding of what life is about. The concepts and generalizations around which the effective "problem-centered" course is built are useful to young people because they provide purpose and meaning in living. We do not mean blind problem solving, or fruitless problem doing, but problem solving, problem doing, drill (practice), and inductive-deductive work—all toward the formation of concepts which help youngsters do a better job of living (see Chapter 6).

A synthesis

What then is the orientation to which we may repair? Here historical perspective helps us to help ourselves. *Historical perspective shows that even the most modern orientation, based on current research and educational invention, will one day be termed traditional and be supplanted by devices which will be even more significant and effective.* This is in the nature of advance. We take the best of the old, and blend it with the best we know from later studies.

But "the best we know" is not always "the best we should know." Education, its psychology as well as its pedagogy, has not advanced to the point where we can demand of our theories, as rigorously as we should like, that they show us when we are wrong. We propose that a fitting base for the objectives we seek as science teachers lies in:

A conception of the way children grow and what they need to know to develop to their fullest in this modern world.

A conception of the "real" world as scientists have described it. We understand this to be a tentative, always changing description.

A conception of the way of the scientist as he seeks to understand the world.

This base is oriented in generalizations about the growth of children (developmental tasks), in generalizations about the "real" world (concepts), and in the process by which developmental tasks and generalizations about the world we live in are discovered (the way of the scientist).

Now, of course, no one knows just how children grow, or what they need to know to grow to their fullest, or what the world really is like, or the full

evidence For and Against each item Look again at the five contentions in terms of the children you teach will teach, or used to know when you were in secondary school Look once more to see to what extent the adoption of each point would dictate or restrict the manner in which you would organize and teach the subject matter Even if all five points were operating simultaneously, what opportunities would exist for your personal inventions in teaching procedures?

The textbook, of necessity, is usually based on a blend of most of these five factors Certainly authors have difficulty in introducing new materials, fresh content, or new approaches. Teachers, who choose the books to be used, demand that a new textbook *must* include most of the old familiar materials, even as it grows too large by the addition of "new topics." Authors are caught in a vise. Major changes in texts come slowly, but they do come. Some have said that this slow change in textbooks is a guarantee that the changes in curriculum will be slow but sure.

Teachers who reject the five shackles listed above, and want to alter their selection of instructional material may do so. Ample materials of varied approach are available in texts and supplementary works (see Section III).

A base in the generalization approach

Appraisal of the teaching of science has stimulated various attempts to make field covering more coherent. These resulted in what may be called "the generalization approach" to curriculum construction. Essentially, the major concepts and conceptual schemes of a field of science would form the center of crystallization for the subject matter in that field. The experiences, activities, knowledges, and skills would *be organized* in such a manner that they would form an inductive pattern, leading inevitably to the desired generalizations. Thus, the generalization, *matter is composed of submicroscopic particles*, would be central to teaching a whole area.[8]

The generalization approach is oriented toward field covering by providing centers for the organization of subject matter into a curriculum. But a verbal familiarity with generalizations can be just as lacking in meaning for improving the quality of living as subject matter organized to meet the demands of passing an examination. In other words, teaching generalizations as ends in themselves seems just as sterile as teaching content to pass examinations.

We are faced with still another difficulty in the formulation of our objectives; a difficulty perhaps partially responsible for the troubles mentioned above. Some stated objectives stress the *internal or mental*, and invisible, changes sought in students. These are phrased as Understandings, Generalizations, and Concepts They are drawn from the *results of past science, the history of science*, as it were. These concepts, in other words, have been previ-

[8] National Society for the Study of Education, *Thirty First Yearbook*, U. of Chicago Press Chicago, 1932 A number of such generalizations in all areas were stated in this work.

3. The ways of the scientist as they help boys and girls understand the impact of science and scientists on society.

Otherwise why would the community "now stress science"? And "work closely with business," which as always depends on technology whose roots are in science? Furthermore, what kind of science instruction should be given the 70 per cent of youngsters who are not going on to college? And what kind of science should be given the 30 per cent who are going on to college—a few of whom may become scientists?

We propose that "The aim: to train the 70 per cent of high school graduates who don't go to college" and the succeeding phrases indicate a turning to the objectives of general education. This in no way means a turning away from "standards"; it does mean for science specifically a synthesis around the three elements we have stated above. General education is concerned with developing the various individuals we teach so that they will be able to utilize their capacities in planning and living their own lives with competence. The developmental tasks are aimed at this goal, and so is our synthesis.

But the synthesis we have suggested does not explicate the kinds of things students need to do to live their lives fully. Quotations from individuals who have given this kind of explication serious thought would be useful. [5]

> The purposes of general education are better understood in terms of performance or behavior rather than more narrowly in terms of knowledge.

And the 1952 Yearbook of the National Society for the Study of Education, *General Education*, includes this quotation: [6]

> President Conant states he would amend the Harvard report, *General Education in a Free Society* . . . by stressing the *type of behavior* [italics ours] on which a free society depends rather than emphasizing the common knowledge and common values which influence the behavior of citizens.

In other words, without definite specifications of the kinds of behaviors which students should develop as a result of *taking a course*, teachers comfort themselves with delusory notions that as long as students take science courses they will somehow come out sound of mind and of body, and that they will do the things expected of them.

We lean to the notion that a person's *knowing something* can best be determined by his *doing something*. Briefly, we suggest that desired changes in behavior be expressed as *behavioral objectives*.

The behavioral objective

We educate in order that we may improve the quality of knowing, of understanding, of the behaviors which lead to more effective living. In other

[5] T. R. McConnell *et al.*, "General Education," *Encyclopedia of Educational Research*, ed. by W. S. Monroe, Macmillan, N. Y., 1950, p 489.

[6] *Fifty-First Yearbook*, Part 1, U. of Chicago Press, Chicago, 1952, p 6.

words, if education is effective, it results in a *change in behavior* which effects an improvement of living. We shall refer to objectives (which we always associate with a change in behavior) as *behavioral objectives*. This is an appropriate term which we gladly borrow from other recent publications.

The Russell Sage Foundation has supported two projects, "Elementary School Objectives," and "Secondary School Objectives." These are available to any teacher for a study of the behavioral objectives which have been developed as a consensus by "experts" in elementary[7] and secondary education.[8]

An examination of several *samples* of behavioral objectives, as stated by N. C. Kearney and Will French, will indicate their structure. This in turn may aid the reader in elaborating his own objectives (see the "Excursion" at the end of the chapter). In this last section, we state objectives, *not* by way of sample or of example, but to afford those teachers who want to do so an opportunity to develop their own statements of objectives. We feel quite firmly that a textbook in the methods of teaching science should avoid statements of objectives. These, above all, must stem from the community, the school, and the teachers. (Note: The emphasis is on knowing and understanding as behavioral objectives.)

Case 1. Sample objectives in elementary school science[9]

KNOWLEDGE AND UNDERSTANDING

Intermediate grades. He [the student] is beginning to understand how physical features and resources affect population, conservation, recreation, industry, prosperity, aggression. He is able to contrast recent and ancient ways of living. He knows that man derives wealth from animals and from the earth. He knows the functions of the weather bureau, biological survey, geographical society. He understands that scientific progress is generally a cooperative enterprise. He knows the relative locations of the major regions of the world and is able to interpret many of the common natural phenomena. He is beginning to develop a store of knowledge about agriculture, mining, dairying, and manufacturing. He knows about and uses safe behavior with firearms, explosives, poisons, noxious weeds, poisonous plants, and such "unknowns" as dynamite caps, radium pellets. He should have a reading vocabulary of 500 history and geography words, and a recognition vocabulary of an additional 300.

He knows some ways of verifying data to distinguish between fact and opinion. He is beginning to search for "how" and "why" generalizations in what he observes in the natural world about him.

He is beginning to understand the ways in which man has gained control over his environment and has made adaptations to it, and he relates this control to the development of science and civilization as we know them.

SKILL AND COMPETENCE

Upper grade period. He uses scientific information in a broad range of activities about the home relating to diet, appliances, equipment, gardens, auto-

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[7] Nolan C. Kearney, *Elementary School Objectives*, Russell Sage Foundation, N. Y., 1953.

[8] Will French *et al.*, *Behavioral Goals of General Education in High School*, Russell Sage Foundation, N. Y., 1957.

[9] N. C. Kearney, *op. cit.*, pp. 88, 92-93.

mobile, furnace, ventilation, lighting, insects and pests, pets, winter and summer chores, faucets, and conservation.

He habitually associates facts and seeks to formulate generalizations in the social and the physical environment. He is careful to try to ascertain the difference between real facts and the conclusions they seem to suggest (in geography, for instance). He uses scientific method in seeking conclusions and finding answers. He distinguishes scientific method from superstition, magic, astrology, legend. He performs simple experiments in school and at home to satisfy curiosity about scientific questions. He seeks information as to safe rules for performing experiments

Through reading, experimentation, and discussion, he examines the meaning and implications of new developments in such fields as electronics, plastics, jet propulsion, aircraft, and atomic energy.

Note that the child *does* things as a result of teaching: "He uses safe behavior with firearms," etc. It is never enough to state an objective in this way: "The teaching of the rotation of the earth so that the child understands time." The aim must be explicated by an activity, a change in behavior: in a behavioral objective.

We turn now to several cases of behavioral objectives dealing with the secondary school.

Case 2. *Sample objectives in high school science* [10]

[STUDENT] TAKES INTELLIGENT ACTION ON HIS HEALTH AND HYGIENE PROBLEMS

Some illustrative behaviors Regularly seeks advice from medical and dental practitioners and specialists, secures medical and dental examinations, not less than once a year and more often in case of need.

Uses good judgment in deciding when symptoms of illness in self or others warrant consultation with a medical adviser, and assists the doctor or dentist by defining his symptoms.

Avoids self treatment of acne or other functional disorders common to youth.

Utilizes when necessary the health services of the community and helps others to do likewise.

Takes measures such as vaccination and immunization to protect his health and that of others from communicable disease.

Maintains (if girl) good habits of cleanliness, health, sanitation, and sensible exercise relating to menstruation.

Recognizes the hazards of quack or "patent medicine" medical care and of the comparable charlatan in mental health care, and seeks to avoid these approaches to mental and physical health care

Refuses to try a habit forming drug and reports to the proper authority anyone offering one to him.

Plans for adequate ventilation in all indoor situations.

Establishes habits of regularity in the elimination of bodily wastes.

Takes measures to protect himself and others when suffering from a cold or other infectious diseases.

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[10] W. French, *op. cit.*, pp. 118-20.

Developmental equivalents (Expectations for younger or less mature students)

Uses simple first aid measures in dealing with minor injuries. Uses simple hygiene procedures.

Has made some effort to improve his physique and appearance.

Knows some common harmful conditions that affect health adversely, [such as] poor diet, lack of sleep, etc.

Spends much of his leisure in team-play sports but is not conscious of health benefits.

Accepts aids or devices (e g orthodontic braces) that will improve his physical appearance later

Is gaining an understanding of the principles governing good eating habits and of the need for rest and physical activity

Desires to conform to standards of dress set by own sex group, but is becoming discriminating about this respect.

Cooperates with parents by adhering to a diet if he is too thin, too fat, or has physical disorders.

Observes the principles of hygiene in the care of skin, teeth, hair, eyes, and ears, etc.

Recognizes need for some "rules" about his work, play, diet and sleep

Is learning to dress becomingly

Assumes good posture for his growing body

Recognizes desirability of consulting a physician and dentist periodically.

Does not believe everything he hears about health on TV and radio, or reads in print

Is wary of patent medicines without checking with proper authorities.

Disapproves of the misuse of drugs

Understands the negative aspect of the use of tobacco and alcohol, and uses neither.

Note the use of *active verbs* A behavioral objective is a behavior; it is something which can be observed because youngsters show it in *a form of action*. To repeat, if the objective is attained, it can be seen in action; it can be seen as active in the lives of youngsters who have been "taught" and have "learned."

Case 3. *Sample objectives in adjusting to scientific conditions*

Now note how Stratemeyer and her colleagues state these objectives (Table 5-1, p. 98). Note that they provide for differences in the age of individuals, that is, they expect that growth has occurred and some of the developmental tasks have been approached and mastered to a degree.

What value has this for us as teachers of science? Considerable value even when examined casually. To begin with, an objective stated in behavioral terms, in terms of what youngsters can be seen to do, helps the teacher plan *specifically to do what he can to help* youngsters change their behavior. Secondly, the attainment of an objective stated in terms of specific behaviors can be appraised with greater objectivity because it can be observed. Like the scientist, we see a different reaction and can then ponder how it came about

Thirdly, and most important, the formation of behavioral objectives demands a thorough insight into the life and living of youngsters in their community. Youngsters are more ready to help in planning when they can anticipate a desired change in their own lives. Furthermore, behavioral objectives are clearer goals for youngsters to seek; they can recognize the importance of the desired behaviors and assess their own growth in these directions. Now let us look into the patterns which behavioral objectives take.

Patterns in behavioral objectives

The reader may say that these three cases we have included for study are really "outcomes" and not "objectives." This is begging the question in the following ways. Objectives are often stated in the form: "to know," "to understand," "to appreciate." But how can one tell whether this has been accomplished? One tests the student. Consequently teachers' *real* objectives appear on their tests and in the behaviors they seek in class, in the laboratory, and in the "world." Students see this clearly; some (college students) have been known to say, "I didn't know what the course was all about until I saw the final examination." (This is, of course, not the most desirable situation!) All this then puts great importance on evaluating procedures, for these reveal the teacher's real objectives. For this reason Section IV is concerned with the appraisal of students, and of the teacher's role.

While there are no "average children" and no "average competence," we nevertheless tend to expect excellence of all, as if all could achieve excellence as well as aspire to it. But aspiration to excellence is not equivalent to its achievement. In developing a pattern of behavioral objectives which will guide us in our derivation of a pattern which fits each of us individually, *we must guard against expecting uniformly the highest attainment of our objectives from all our students as well as ourselves.* Those of us who have lived long enough have had occasion to rue our frequent fall from the heights, and to wonder whether we shall ever reach the real heights.

First we need to classify our objectives into at least two groups. Careful examination of courses of study shows that the numerous objectives differ in at least one major aspect. Some apply to the entire course; indeed some apply to all of schooling. These we shall call *pervasive* objectives. The others are limited to a particular course of study, even to a unit of work. These we shall call *limited* objectives.

Each objective as stated will consist of two parts: the internal-intellectual *and the* external-observable. *Behavioral objectives,* as we *shall* formulate them, are phrased in the form INTERNAL: *observable.* That is, an understanding (the internal) is followed by a skill or competence (the observable).

The teacher who formulates his objectives in the pattern will thus have each explicit understanding followed by one or more observable, overt activities which require that understanding.

TABLE 5-1 ***A set of behavioral objectives: adjusting to atmospheric conditions*** *

	EARLY CHILDHOOD	LATER CHILDHOOD
Understanding Weather Conditions	*Finding how changes in weather affect one's activities:* Reading a thermometer; finding how to protect hands when playing in snow; finding what snow, rain, hail, sleet, clouds are like; helping decide whether it is likely to rain; asking how parents or others tell that it may rain or be clear later in the day; finding what clothing is appropriate to a variety of weather conditions; inquiring about frost or steam on the window pane; keeping simple weather charts; etc.	*Developing bases for judging and adjusting to weather conditions:* Reading thermometer, barometer; finding how to interpret reports from weather bureau; testing superstitions about the weather; finding what causes thunder, lightning, hail, rain, snow; inquiring about the causes of reported hurricanes, cyclones; finding why mountains have snow on them in summer, why sheltered parts of garden do not freeze; helping cover plants in garden before a freeze; helping parents prepare for winter weather; asking about differences in climate reported in articles about other countries; etc.
Adjusting to Conditions of Air, Moisture, Sunlight	*Noting effects of different atmospheric conditions:* Helping ventilate rooms; providing adequate ventilation for a pet to be taken on a train; finding why strong winds make it hard to walk; asking where winds come from; asking how birds, airplanes can stay up in the air; finding when it is necessary to protect oneself from sunburn; etc.	*Finding out about phenomena associated with the atmosphere and reasons for common adjustments:* Finding how to avoid drafts in ventilating a room; finding why humidifiers are used at home, in school; using basic principles in flying a kite, flying toy airplanes; discussing how fresh air is supplied to submarines, deep sea divers; discovering why protections against sunburn are more necessary when near water; etc.

* Florence B. Stratemeyer, Hamden L. Forkner, Margaret G. McKim, and associates, *Developing a Curriculum for Modern Living*, Bureau of Publications, Teachers College, Columbia University, N. Y., 1947.

We are, of course, aware that having an understanding itself is a behavior and that achieving an understanding, where none existed before, is a change of behavior. We insist, however, that while this is all to the good we should like to have *evidence* of this achievement of a change in understanding. This evidence is best obtained, where possible, through observation of an overt behavior.

YOUTH	ADULTHOOD	
Understanding climatic and weather conditions and making appropriate adjustments. Understanding the principles in operation in barometers, other instruments to predict weather, reading weather maps, discussing the reasons for regular occurrences of hurricanes, cyclones, floods in specific parts of the country; discussing the adequacy of community provisions against these disasters; helping parents decide on the kind of crops, plants, trees, which will thrive in the prevailing climate, finding how houses are built to take account of different weather conditions; discussing reports of the effects of drouth, excessive rains on the nation's food supply, discussing the possible effect of prevailing weather conditions on the location and use of international air lines; etc.	*Making effective adjustment to weather and climatic conditions.* Using appropriate instruments to predict the weather: the thermometer, barometer, weather bureau; deciding on appropriate clothing for self, children, deciding whether prevailing conditions make hail, wind, flood insurance or special protections desirable; adjusting style of house to prevailing climatic conditions, adjusting kind of crop and garden to length and nature of season, deciding where and when to take vacations; considering the possible effect on price and availability of raw materials of unusual weather conditions in this or other countries, etc.	*Understanding Weather* Conditions
Using basic principles governing needed adjustments to atmospheric conditions. Ventilating home, schoolroom; discussing the issues involved in proposed measures to assure smoke control in industrial cities, discussing new discoveries which prolong the time man can stay in rare atmospheres, under water; finding how air conditioning can control heat and humidity; finding why dry warm climates are recommended for certain illnesses, etc	*Making effective adjustments to atmospheric conditions* Deciding how best to ventilate a house, office; deciding when a humidifier is needed, considering whether to install air conditioning; taking action to control smoke in industrial cities; finding what adjustments to make in moving to different altitudes; taking action on measures to rid the atmosphere of pollen; adjusting activities in hot humid weather; helping children avoid sunburn; etc.	*Adjusting to Conditions of Air, Moisture, Sunlight*

An example of a pervasive objective stated in this pattern (as a behavioral objective) would be:

Understanding: *behavior*

To understand that an effect generally is related to a cause: *in his explanation of events (e.g., rain) he [student] states a cause (cold front) or states a hypothetical cause, or states that the presumed cause is unknown to him.* Clearly this applies to all science courses; it is a pervasive objective in all of science teaching.

Examples of limited objectives (which in their turn serve pervasive objectives) are:

General science

TO KNOW GENERALLY THE GEOGRAPHY OF THE SKY: *he identifies the common constellations.*

Biology

TO KNOW THE BASIS OF NUTRITION FOR GROWTH AND HEALTH: *he plans a satisfactory diet for himself for a three-day period.*

Chemistry

TO UNDERSTAND THE CONCEPT OF pH *he determines the acidity of his lawn or a sample of soil, distinguishes between common acids and bases found in the laboratory and the home; knows first aid procedures for accidental contact with stronger acids and bases.*

Physics

TO UNDERSTAND OHM'S LAW: *he does expected calculations involved; applies Ohm's principles to parallel and series circuits, practices safe loading of circuits.*

These are but a few examples; surely many others will occur to the reader. We do not plead the importance of these particular objectives, although we could develop the pervasive objective to which they apply. For instance, Ohm's law could well illustrate the pervasive objective of teaching "cause and effect" relationships. (Of course teachers will prefer their own "limited" objectives.) What we feel is important here is the utility and clarity of the objectives when stated in this form. They state an intellectual generalization or understanding and also state immediately thereafter the behaviors to be observed when the student knows the meaning of the generalization.

But what of attitudes and appreciations? As attitudes and appreciations change they are exhibited in long-term, habitual behaviors of the learner. Essentially they represent the emotional orientation of the individual toward the topic at hand They are the guide lines with which he approaches the information and weighs the various facts available to him. Most of the attitudes sought in science courses, and in all schooling, are pervasive; but these necessarily develop out of specifics which are initially limited. Our form of stating attitudes is:

ATTITUDE: *activity*

Pervasive

TO DEVELOP AN ATTITUDE OF OPEN-MINDEDNESS *in expressing judgments where the data are obviously incomplete, tends to say something of the sort "all the facts are not in; let's wait"; wants to hear both sides of the case; forms tentative conclusions.*

Limited

TO CONSERVE LIVING THINGS: *in the field builds campfires properly; stamps them out after use, cleans up after a meal; checks safety devices at home.*

The attitudes we develop in children are, however, intended mostly to be pervasive, rather than limited. Note also that the methods of approaching science, the ways of the scientist, are pervasive, whereas generally speaking, concepts, facts, and data tend to be limited or contained within a subject area, or a single topic. Conceptual schemes tend to be less limited; in fact, in the general courses such as general science, they tend to be pervasive throughout the course.

Patterns of objectives in relation to a science teaching pattern

In Section III, where we study the science curriculum and its scope and sequence, we shall consider a number of specific behavioral objectives in science. In this chapter, our purpose is to consider how a pattern of objectives relates to a pattern of teaching. Additional specific methods, techniques, and procedures related to teaching patterns affecting science-shy and science-prone students will be presented in Chapters 8 and 9.

The beginning teacher

A beginning teacher has not yet formed his teaching pattern, but he soon will. To be sure, he will undertake to teach the ways of the scientist, to institute the climate of science in his classroom, and to work for concept attainment by his students (Chapter 6). Initially he will be aware of the three general teaching patterns described in Chapter 4: the dominating, the laissez-faire, and the democratic planning. Each has its appealing attributes to the relatively insecure beginner. Which will he choose and why?

He will ask himself, "What do I really want to accomplish in my teaching?" Or to put it another way: "What are my responsibilities to these children? What are my real purposes?" We believe that the form of answer which will have most meaning to him will be stated as behavioral objectives: what he wishes the students to learn to do and the basis on which they do those things. Such objectives are not quickly isolated and phrased. Gradually they evolve through careful study, thought, discussion, and reflection upon experience. Mature teachers have learned that they continually outgrow their older objectives; new possibilities always come to light. The beginning teacher should expect throughout his teaching responsibilities to modify continually his objectives as he learns more about children and the subject he teaches. Such a continual search gives purpose and direction to his study and thought. The ability to extend and enrich objectives is one hallmark of the professional teacher. A teacher's analysis is never completed; and this is one reason that teaching is exciting.

Be that as it may, the new teacher enters a teaching environment (school and community) in which a certain teaching pattern is praised and in which

Examples of limited objectives (which in their turn serve pervasive objectives) are:

General science

To know generally the geography of the sky: *he identifies the common constellations.*

Biology

To know the basis of nutrition for growth and health: *he plans a satisfactory diet for himself for a three day period.*

Chemistry

To understand the concept of pH: *he determines the acidity of his lawn or a sample of soil; distinguishes between common acids and bases found in the laboratory and the home; knows first-aid procedures for accidental contact with stronger acids and bases.*

Physics

To understand Ohm's law: *he does expected calculations involved; applies Ohm's principles to parallel and series circuits; practices safe loading of circuits.*

These are but a few examples; surely many others will occur to the reader. We do not plead the importance of these particular objectives, although we could develop the pervasive objective to which they apply. For instance, Ohm's law could well illustrate the pervasive objective of teaching "cause and effect" relationships. (Of course teachers will prefer their own "limited" objectives.) What we feel is important here is the utility and clarity of the objectives when stated in this form. They state an intellectual generalization or understanding and also state immediately thereafter the behaviors to be observed when the student knows the meaning of the generalization.

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Attitude: *activity*

Pervasive

To develop an attitude of open-mindedness: *in expressing judgments where the data are obviously incomplete, tends to say something of the sort "all the facts are not in; let's wait"; wants to hear both sides of the case; forms tentative conclusions.*

Limited

To conserve living things: *in the field builds campfires properly; stamps them out after use, cleans up after a meal; checks safety devices at home.*

As we have stated in Chapter 4, the laissez-faire approach generally results from a basic misunderstanding of the so-called progressive approach. Generally it is soon relinquished as vague, frustrating, and chaotic.

Objectives related to the pattern of democratic planning. A teacher who works in this pattern looks at the youngsters and the area of subject matter he teaches with the eyes of a responsible citizen, a leader of youth, rather than as a subject matter specialist or an amateur psychologist. He starts with human beings, his students—with their needs, problems, concerns, interests, motivations—and asks how his subject matter specialty can help them to live better lives. He consults his students, his community, his supervisors and administrators, the archives of his subject matter area, himself (in the light of his experience).

Such a teacher actually deals with behavioral objectives. For as he consults those elements of his teaching environment listed here, he perforce comes to realize not only that his teaching must affect those he teaches, but also that he must demonstrate the effectiveness of that teaching. He comes to realize that he must weigh the results of his teaching; because even as he evaluates his students, they also evaluate him, in much the same way that their parents and the school administrators do.

Therefore he states his objectives and the behaviors he expects when these objectives have been attained.

The patterns of objectives, which best fit the teacher who is within the pattern of democratic planning, are those stated as behavioral objectives. Whether the objectives he states are pervasive and sustained throughout the entire course or curriculum, or whether they are limited and contained within a unit or part of the course or curriculum, these objectives, or goals of instruction, are most clearly stated wherever possible in the pattern we have suggested:

UNDERSTANDING. *skill (or competence)*

ATTITUDE: *activity*

Objectives stated in this pattern clarify each other in counterpoint. Skills operationally define and clarify the understandings, and the activity shows that the attitude is indeed a part of the individual's behavior. For what does it profit us to state objectives unless they result in observable changes of behavior?

One pattern of behavioral objectives: "critical thinking"

A very interesting analysis of "critical thinking" was made by Burke:[11]

> A person carries on critical thinking when he exhibits the following behaviors:
>
> 1. Differentiates between authoritative and nonauthoritative (reliable and less reliable) sources of information.
>
> 2. Criticizes faulty deductive reasoning.

[11] Paul J. Burke, "Testing for Critical Thinking in Physics," *American Journal of Physics*, 17, 527, 1949.

certain objectives are prized. He cannot, and should not, attempt to alter these until he has lived with them for a while. Our explicit statement then for the beginning teacher is to adapt to the teaching pattern and to adopt the teaching objectives of his environment, for the first year or two. These are years of study and choice, much like the first few years of the residency of a physician or the apprenticeship of a young attorney.

After the first years

In Chapter 4 we stated our preference for the pattern of teaching which we consider most effective, this is based on years of trial, error, observation, and much practice. This will be made more specific in Chapters 8 and 9, because both the science shy and the science prone react most favorably in this pattern. In our experience, the patterns of laissez-faire and domination are not as effective with these groups, or with the general run of students.

Objectives related to the pattern of domination. The dominating teacher derives his objectives from subject matter. When these objectives are stated by such a teacher, they appear with such forms, tones, and overtones as the following:

"To learn the principles of chemistry."

"To practice the method of the scientist."

"To learn to do weight volume problems."

"To learn to classify animals and plants."

"To learn the anatomy of vertebrate animals."

"To learn the principles underlying the laws of machines."

Sometimes (and we ourselves have heard these) the objectives are stated as bluntly as follows:

"We prepare them for college."

"We prepare them to pass the College Board Exams."

"What's the difference as long as they work hard? Almost anything they learn is good for them."

Objectives related to the pattern of laissez-faire. Strangely enough the objectives of the teacher who holds to laissez-faire may relate closely to the last "objective" stated above:

"What's the difference what they learn, as long as they grow, and learn to live with each other?"

The teacher who maintains a laissez faire approach is very likely, if he persists, to approve of such objectives as these, generally stated by his pupils:

"I want to grow rats." (The teacher sees in this an opportunity for the youngster to learn something of the nutrition, growth, and reproduction of animals and to develop certain attitudes and appreciations.)

"I want to study photography." (The teacher sees in this an opportunity for the youngster to study some chemistry, to develop habits of work, in addition to certain attitudes and appreciations.)

An excursion into developing one's own statement of objectives

Some teachers may be interested in developing their own objectives. Two selected cases are presented below, and another cited, for this purpose.

Case 1

The following list of objectives of science teaching has been set forth by R. Will Burnett.[12] These are relevant to an area of need which Burnett stated as follows: "It is desirable that young people develop scientific or critical attitudes and abilities." This is a component of the larger developmental task of young people which involves their development of a personal philosophy or "world view."

Now let us look to Burnett's list of objectives which stem from this need:

1. Ability to discover problem situations.
2. Ability to delimit problems into workable and procedural proportions.
3. Ability to develop critical hypotheses.
4. Ability to secure expeditiously relevant, authoritative reference data.
5. Ability to secure experimental or observational data critically and expeditiously.
6. Recognition of bases of authority in any field.
7. Ability to work cooperatively.
8. Ability to recognize personal bias and to consider it in making judgments.
9. Disposition to allow ascertainable facts to speak louder than prejudice.
10. Ability to communicate effectively and accurately.
11. Recognition of limitations of both data and conclusions.
12. Willingness to reopen issues if new data are available.
13. Recognition of approximate nature of truth.
14. An explicit understanding of major aspects of "the scientific method."
15. Recognition of applicability of scientific methods to many nonscience problems.
16. Recognition of essential synonymity of scientific and democratic procedures.
17. Recognition of necessity for planning on complex issues.
18. Recognition of universality of cause and effect relationships.
19. Aggressive interest and ability in determining causation even in complex and controversial fields.
20. Critical understanding of differences in several historical and contemporary conceptions of truth and in methods of formal inquiry: scientific method, magic, supernaturalism, reason, observation, experimentation in discrete areas, trial and error discovery, scientific planning, and pragmatism.
21. Faith and allegiance to the scientific method as against narrow, piecemeal understandings of it or awe inspiring, glamorous, "almost magical" conceptions of science and professional scientists.
22. Recognition of limitations of scientific methods particularly when ap-

[12] R. Will Burnett, "The Science Teacher and His Objectives," *Teachers College Record*, 45, 211, Columbia U., Jan. 1944.

3. (a) Differentiates between statements that describe observations, i.e., "facts," statements which are hypotheses about facts, and statements that introduce new words

(b) Recognizes meaningless statements, e.g., *statements which are not definitions*, are not verifiable by observations or do not have implications verifiable by observations, and are not mathematical or logical propositions

4. (a) *Draws valid* inferences from graphs, tabular data, expository material, and other given information.

(b) Recognizes what assumptions are to be maintained in drawing inferences from data.

5. Selects data which are pertinent to a problem.

6. Criticizes data (tabular, graphical, or other) which have been collected to aid in the solution of a problem, with respect to:

(a) pertinency to the *problem*,

(b) accuracy of the data and reliability of the method of collection,

(c) sufficiency

7. Criticizes inferences drawn from data by recognizing whether a supposed inference is an implication of the data, unrelated to the data, or contradicted by the data

8. Estimates probability of the inference and criticizes given estimates of probability

9. Selects the hypothesis, from a group of hypotheses, which most adequately explains given data

10. *Recognizes the approximate or tentative nature of* hypotheses.

11. Recognizes what assumptions, beyond the data, have to be made in the formation of hypotheses

12. Criticizes hypotheses as to:

(a) accordance with the data,

(b) adequacy of explanation.

13. Criticizes experimental procedures as to:

(a) *pertinency of the procedure to the problem*,

(b) isolation of the experimental variable by proper controls,

(c) accuracy of the observations,

(d) sufficiency of the number of observations or repetitions of the experiment,

(e) validity of the assumptions involved in setting up the experiment.

14. (a) Recognizes the existence of errors of measurement.

(b) Recognizes when the precision of measurement given is of a degree *warranted by the nature of the problem*.

(c) Criticizes a stated precision of measurement according to the precision of the measuring instruments used.

15. (a) Recognizes what assumptions have to be maintained in generalizations from the results of an experiment.

(b) Criticizes the validity of generalizations from the results of an experiment to new situations, according to the degree of similarity of the new situation to the experimental situation

Notice that no particular subject material is cited, the behaviors described are required in many areas of science. Perhaps you will find it useful to examine certain of these listed behaviors in terms of how they could be practiced by students in the courses you teach, or plan to teach. These behaviors listed by Burke are drawn *from the dynamics of science; to us they are science*. Opportunities to practice them are inherent in all the subject material of the sciences.

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4. Ability to secure expeditiously relevant, authoritative reference data.
5. Ability to secure experimental or observational data critically and expeditiously.
6. Recognition of bases of authority in any field.
7. Ability to work cooperatively.
8. Ability to recognize personal bias and to consider it in making judgments.
9. Disposition to allow ascertainable facts to speak louder than prejudice.
10. Ability to communicate effectively and accurately.
11. Recognition of limitations of both data and conclusions.
12. Willingness to reopen issues if new data are available.
13. Recognition of approximate nature of truth.
14. An explicit understanding of major aspects of "the scientific method."
15. Recognition of applicability of scientific methods to many nonscience problems.
16. Recognition of essential synonymity of scientific and democratic procedures.
17. Recognition of necessity for planning on complex issues.
18. Recognition of universality of cause and effect relationships.
19. Aggressive interest and ability in determining causation even in complex and controversial fields.
20. Critical understanding of differences in several historical and contemporary conceptions of truth and in methods of formal inquiry: scientific method, magic, supernaturalism, reason, observation, experimentation in discrete areas, trial and error discovery, scientific planning, and pragmatism.
21. Faith and allegiance to the scientific method as against narrow, piecemeal understandings of it or awe-inspiring glamorous, "almost magical" conceptions of science and professional scientists.
22. Recognition of limitations of scientific methods particularly when ap-

[12] R. Will Burnett, "The Science Teacher and His Objectives," *Teachers College Record*, 45, 241, Columbia U., Jan. 1944.

plied to areas where control is difficult and where contingencies and imponderables are numerous

23. Understanding that although science may determine which of alternative defined goods or bads are most conducive to the outcomes specified in the definitions, science itself cannot determine what is good and what is bad. Recognition that the pragmatism of science is a method and a philosophy, but that moral codes depend upon ethical considerations that are, in part, of a different order from science.

Now if some of the objectives above are written in our formula for behavioral objectives, they might look like this

7. *Ability to work cooperatively* among other things, works without friction with partner in the general science, chemistry, physics, or biology laboratory, takes effective part in class committee work and contributes his share; helps build an exhibit; does his share in keeping the classroom clean; takes his turn in feeding classroom animals.

9. *Disposition to allow ascertainable facts to speak louder than prejudice:* when he doesn't know, states, "I don't know"; reacts to acts of racial bias by asking "What are the facts?". In his class discussions, tends to try to ascertain the facts; questions background of sources of statements which show prejudice; brings in newspaper articles which report acts of prejudice (where scientific base can be ascertained) for discussion in class.

18. *Recognition of universality of cause and effect relationships:* uses if-then relationship, questions explanations which involve animism, anthropomorphism, or teleology, or are untestable; when confronted by "superstition," looks for observable cause-effect relationship; in specific problem situation (problem doing), searches for cause when the effect is given (e.g., lightning: thunder, clouds. rain, germ. disease; vitamin deficiency; avitaminosis; hemoglobin defect anemia, defective fuse: power failure; etc.).

5-1. Try your own abilities by stating one or more of the remaining "objectives" as *behavioral objectives.*

5-2. Inspect the objectives of a course of study you are teaching, or will teach, and state them as behavioral objectives.

Case 2

The aims of a curriculum, or its objectives, may be stated in ways other than "behavioral objectives," although our own preference is clear. They may be stated not only as "needs" but as "problems of living." One such statement fully developed is that upon which *The Curriculum Framework for Georgia Schools,* Atlanta, 1954, is based.

Essentially, the major problems of living selected apply to all levels of the curriculum from kindergarten through adult education. These are:

Achieving and maintaining physical and mental health
Making a vocational choice and earning a living

Performing the possibilities of citizenship
Conserving and utilizing resources
Communicating information and ideas
Expressing aesthetic values

Note that these might easily be called "developmental tasks."

The teachers and curriculum consultants who proceeded to develop each of these problem areas programed some "Suggested Experiences based upon Objectives of Education and Growth Characteristics at Various Levels of Development."

For instance, note in the sample that follows on the problem area, "Conserving and Utilizing Resources," how the teachers developed differing activities or "experiences" for various groups ranging from the kindergarten through the secondary school to adult education courses; we quote only the portions dealing with grades 7-12. While the particulars useful for Georgia may not be useful for Massachusetts, Texas, California, or Illinois, the approach is applicable anywhere to any subject.

CONSERVING AND UTILIZING RESOURCES[11]

Lower secondary grades 7-8-9

1. Developing and applying plans for preventing or controlling erosion on the school grounds or on community playgrounds and parks.

2. Cooperating with local agencies in developing plans for reforestation in the community, insect and rodent control, and stocking ponds and streams.

3. Discussing protective agencies, such as the State Board of Health, Welfare Board, local hospitals, and the procedures for securing help from these agencies.

4. Making individual time and activity studies to see if the time and energies of each are being used to best advantage.

5. Visiting a cold storage plant and other industries to see how man has found better ways of conserving resources.

6. Inviting leaders of local industries to discuss the various ways in which our natural resources are used, such as cotton and its by-products.

Upper secondary grades 10-11-12

1. Planning and carrying out home and community projects in reforestation, water control, soil building, or other activity dictated by need.

2. Preserving foods, visiting freezer lockers, canning plants and the like.

3. Reading and discussing with people to find out how and why our government controls the use of certain essential natural resources and how government research projects affect local communities.

4. Surveying, cataloging, and using local human resources.

5. Studying and discussing the way man uses "social invention" to develop ways of improving his use of all resources.

6. Interviewing or writing persons connected with the Chamber of Commerce or other civic societies to find out how they influence consumer choices.

7. Reading about and discussing how the choice and use of foods is influenced by the standards set up by health experts.

[11] *The Curriculum Framework for Georgia Schools*, Atlanta, 1951.

8 Studying the development of advertising and its effect on consumer choice.

9 Reading and discussing laws which affect our natural resources.

5-3. These objectives are stated in a form which readily allows them to be restated in the behavioral form we have recommended. You may want to try doing this

5-4. Or restate the "problem area" as a behavioral objective for the elementary school.

5-5. Or restate the "problem area" as a behavioral objective for the secondary school.

5-6. Or state Problem Area C (Citizenship) in terms of several behavioral objectives, say, three or four.

Developing your own objectives

In developing your own objectives, you may find it desirable to examine not only the studies of Kearney,[14] French,[15] and Stratemeyer,[16] but also the studies of a Committee of College and University Examiners titled *A Taxonomy of Educational Objectives,* Handbook I, *Cognitive Domain.*[17] This study includes a classification system, brief definitions of the categories in the system, and a few examples of the objectives belonging in each category.

Use of the taxonomy, as stated by the authors, "can also help one gain a perspective on the emphases given to certain behaviors by a particular set of educational plans. Thus, a teacher, in classifying the goals of a teaching unit, may find that they all fall within the taxonomy category of recalling or remembering knowledge." A study of the taxonomy may give you a new view of the material you have been teaching and its potentialities for helping students act like scientists.

As you approach the selection and statement of your own objectives, you may want to begin by gathering a library of curriculum studies. Note the dates of publication and the variations, between the earlier and the more recent ones, of the form in which objectives are stated. Some interesting examples and discussions appear in various journals of education, e g, *The Science Teacher* and *Science Education.* Others are available, for a small charge, from state departments of education and from cities. The bibliographies at the ends of Chapters 12 through 16 in Section III list many interesting statements for the specific science courses: general science, biology, physics, chemistry, and physical science. Over the years the collection of such a library will be a major factor in the thoughtful consideration which will in turn result in improved science teaching in your school.

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[14] N. C. Kearney, *op. cit.*
[15] W. French, *op cit.*
[16] F B Stratemeyer, *op cit.*
[17] Ed by Benjamin S Bloom, Longmans, Green, N. Y., 1956

CHAPTER 6

Patterns in teaching science:

Winning the concept

A note at the beginning: Poor teaching lacks either soundly conceived objectives or soundly conceived learning activities; the poorest teaching lacks both, the most effective lacks neither. In our experience sound objectives cannot be extricated from the teaching process; the soundness of the learning activity serves the objectives and derives from them. Our experience with beginning teachers and with the improvement of the teaching practices of experienced teachers indicates that, while their objectives are sound, their inadequate notions of what an effective learning activity is often lie at the base of poor teaching. Apparently it is not enough to have sound objectives.

When one looks at learning and teaching, the two sides of the same coin, one recognizes that the *intent* of the good teacher is to help the student develop concepts. We shall propose that the most useful way of doing this is through the learning activity; the student himself goes through the process of forming concepts. Similarly we shall propose that the meat of science, its *content*, is the concepts and conceptual schemes of science.

Then concept formation is the intent of science and the concepts formed are its content. When this intent and this content are fused in teaching (and, therefore, in learning), effective education in science is approached.

The meaning of concept

When a student calls sulfur a metal, when he identifies a circuit as in parallel when it is obviously in series, when he searches for the seeds of a fern plant, it is possible that he has a faulty concept or cannot call the appropriate concept to mind.

The test of the understanding of a concept is appropriate behavior when faced with alternatives, in short, proper interpretation. For instance, understanding of the appropriate concept enables one to choose the proper alternative

Is sulfur a metal or a nonmetal?
Does a fern plant produce a seed or a spore?
Are these connections in *parallel or in series?*

These alternative choices relate to subject matter, it is true, but the ideas expressed relate to other, possibly more important, choices:

Shall I neglect the growth on my skin or go to the doctor? (Depends on an understanding of the concept of normal and abnormal growth of cells.)

Shall I store this inflammable material near the kitchen stove or in a more secluded place away from sparks and flames? (Depends on an understanding of the concept of burning)

Every action is based on a choice, an interpretation (except possibly reflex action). Actions depend generally on an understanding of concepts, appropriately applied.

Concept as pattern. You and I do not attend to everything. We tend to ignore the insignificant, we concentrate on what is significant *to us*, or we disregard what we do not see as fitting our purposes. We tend to see the scene before us as a whole, in terms of relationships, that is, in a pattern As teachers, we see a classroom in activity, with students participating in all ways; we may not notice the single child who is very shy, quiet, not participating A psychiatrist would probably apprehend the situation a bit differently; he might actually "see" the shy child to the relative exclusion of the rest. A spectator watching a baseball game sees Williams or Mantle hit a home run; the coach of the scored against team sees his pitcher's weakness; the happy batter sees his home run total or the disappearance of his slump; the experienced observer sees that the so-called Williams or Mantle shift was not effective.

We organize the scene we are watching, and try to see it as a pattern. Our thought processes seem to call up the simplest pattern describing the scene. This simplest pattern which helps us to order the events around us is a *concept*. A concept is a reduction, in a sense, of events to a recognizable configuration

For instance, HCl, HNO_3, CH_3COOH, H_3PO_4 are acids, and KOH, $Ba(OH)_2$, and $Al(OH)_3$ are alkaline substances We recognize the configurations; we have reduced the pattern of ionizable hydrogen (H^+) to the simplest pattern (for purposes of elementary chemistry), the concept of acid substances. Similarly, OH^- has been patterned in the concept of basic substance. Now this is not the entire concept, but it is a configuration which helps students see a number of facts in a single pattern. By the same token, we can recognize that a concept has been learned, or is operating, by the appropriate response

made to choices (problems) involving the concept. Thus, do we use blue or red litmus paper in testing for an acid? a base?

It would be well at this point to note the difference between a concept and a *conceptual scheme:* A conceptual scheme is a relationship between a number of concepts.

We have a concept when we recognize the common elements in a situation or group of situations (e.g., when we note the MA in a set of different simple machines). Note, however, that we not only recognize and identify the common element, we also ignore the many details in which the situations differ. Thus for the concept of acids we ignored the other ions (PO_4^{---}, NO_3^-, CH_3COO^-).

The two faces of a concept. A concept helps us discriminate, or classify. Thus a goose, a grass frog, a rabbit, a mosquito, a banana plant are classified because we have the concepts of bird, amphibian, mammal, insect, and plant. We have concepts of pulley, fever, and inclined plane, and can classify simple machines accordingly. Concepts then help us discriminate, or classify, or analyze.

The possession of concepts helps us to associate or combine, as well. Thus the goose, frog, and rabbit are also vertebrates; the inclined plane, pulley, and lever are also simple machines. We expect a goose to have feathers and a warm body, and to lay eggs; these are associated in the concept "bird." Concepts, therefore, help us combine, or associate, or synthesize also.

Thus a concept is never a single thing; it helps us achieve *meaning* through discrimination or association. Was it not Einstein who defined science as experience in search of meaning? May we not define science as activity in search of concepts? Concept seeking, together with its end, concept formation, becomes a legitimate, indeed the central, objective of the science teacher.

Concept formation in science

When students of biology first grasp the significance of the concept of "organism," they see it as an organization of protoplasm with a structure serving its specific functions. They see multicellular organisms as being built up of organs; the organs, of tissues; and each tissue, of cells with a similar function. Similarly, if we accept science as consisting of a series of conceptual schemes which help us understand the physical world, then conceptual schemes are made up of concepts; concepts, of a series of related elements or facts; and facts, of the data which result from observation.

A *conceptual scheme* (such as evolution) involves many concepts (e.g., mutation, variation, sedimentation, geographical barriers).

A *concept* includes similar elements, related facts (e.g., the concept of mutation for any specific case includes the related facts of specific gene changes, a related gene, and evidence of a change of that gene into another;

thus the gene for red eye in *Drosophila* changed into the gene for white eye).

A *fact* is based on many observations (e.g., Morgan and his coworkers observed a number of mutations).

A major objective of science teaching is to help students understand the major conceptual schemes which scientists have developed. Curriculum planning (Section III) and lesson planning (this section, Section II) are simplified when teachers consciously undertake to develop a course of study around the major conceptual schemes of the area being considered, and to develop their daily work around the concepts underlying these conceptual schemes. The laboratory and the classroom then become places for discovery, for discriminating and associating data into facts, facts into concepts, and concepts into conceptual schemes. For concepts have meaning when they are applied in discrimination or association.

For instance, the conceptual scheme, "matter is composed of atoms," cannot be derived solely from experience. The concepts built by experience alone in this case may not be entirely correct. A block of wood looks and acts as if it is solid. In the laboratory, however, destructive distillation shows that it is made up of parts, molecules. At least one type of these molecules, water, may be split electrolytically, into oxygen and hydrogen. Thus in the classroom and the laboratory experience is bolstered by deliberate experiment, and the factual data can be built up step by step into conceptual schemes. (A conceptual scheme is about the same thing as a "broad principle," or a "generalization"; for us, however, the term *conceptual scheme* has more meaning.)

Conceptual schemes then are the chief forms of knowledge that science teachers seek to make part of the intellectual equipment of their students. The knowledge gained in understanding such schemes, arbitrary as the area encompassed by any such scheme may be, is transferrable; it may be applied to many situations. Note, for instance, what the understanding of the periodic nature of the elements (a conceptual scheme) confers upon a student in chemistry: the combination of metallic and nonmetallic elements, valence, relative activity of various elements, etc. (concepts).

It is almost obvious that individuals could not discover for themselves all the conceptual schemes already known, and probably not even all they need for daily living in our society. Hence the need for teaching and teachers to re-create efficiently in the young the heritage of the past—both the attained conceptual schemes and the means of attaining them and others of the future.

Concept formation, problem seeking, and problem solving

The teacher of science is often the only science expert in his school community; he is the one who interprets the way of the scientist to his community. We propose to develop in this section the idea that his pattern of teaching needs to be in the mode of science. That is, his course of study, his unit plan, and his daily lesson plan are aimed at the central purpose of the scientist: concept

formation to serve the formation of a conceptual scheme which helps us understand the world in which we live.

Now concept forming includes many teaching activities. There is drill, for instance, to develop skills such as writing chemical equations or solving problems of genetics or solving problems of mechanical advantage. There is review activity of large concepts as they are applied (new view, rather than review). There is the field trip activity, the film activity, the skill activity in the laboratory, and so forth.

Nevertheless, it is our proposition that even simple skill-directed activities are best harnessed in the activity of learning when they have a concept-forming function; the very nature of learning, as we understand it at present, consists of problem-solving activities leading to concept formation. And furthermore the teacher's major function is to use all that is known at present about learning, and to apply it so successfully that young people learn to identify problems and solve them in order to form concepts. These concepts are to be so important, so functional, that their understanding and application leads young people to live more effectively.

The kinds of problems a teacher helps his students identify are coincident with that teacher's *objectives*. The way these problems are solved in the classroom is identified with his *methods*. And the kinds of concepts formed, their scope, and their sequence are identified with the teacher's *curriculum*. It is for these reasons that we propose that a modern approach to science teaching must not consider problem solving alone, but must in the light of learning theory consider also *problem seeking* and *concept formation*.

If our proposition is sound, as it seems to be on the basis of the learning theory to be discussed shortly, then a teacher's objectives will determine the kinds of problems he will help his students identify. If he sees physics as a discipline based extensively on mathematics, he may conceive the problems in terms of quantification only. At once he excludes the science shy (slow learner) from his class; he may even permit himself the luxury of reasoning that his course is college preparatory. He falls into this error, it seems to us, by a curious reversal of logic: he excludes non-college-destined students by the nature of his objectives; now all his students are college-destined. *Quod erat demonstrandum:* his course prepares students for college, and he has evidence of his achievement in that his students do go to college with some success.

On the other hand, a science teacher who recognizes that most of his students, no matter what their future plans, will indeed handle physical apparatus, such as toasters, blenders, vacuum cleaners, radios, TV sets, automobiles, may alter his objectives to include the kinds of problems these young people will meet at home. Since high I.Q., science proneness, and a knowledge of mathematics are not required qualifications for marriage or citizenship, a high degree of quantification and mathematics in physics may not serve these students. Hence the need for different kinds of problems for such students, and in consequence a different degree of expectation in results. For instance, while some students in the physics class might solve complicated circuits using Ohm's

law, it might be sufficient for others to realize that overloading a circuit has its penalties as described by this principle.

Nevertheless, whatever the objectives and whatever the curriculum, neither can be divorced from method. Talk, and it has been considerable, of whether a teacher needs more of method or more of content in order to be at his best ignores our central thesis: problem seeking, problem solving, and concept forming are inextricable. Concepts are formed through the solving of problems; what concepts are formed depends on what concepts are sought. This in turn depends on what problems are sought out or identified, and in turn the concepts formed furnish the matrix, the base upon which further problems are sought. As we have indicated, the tendency of the scientist to seek problems (really concept seeking) has often been called "curiosity."

Learning theory in relation to concept formation

What does a child do when he faces a new, ambiguous situation, that is, a problem? How does he make the new situation part of his experience so that he will be able to cope with it the next time? How does he go about solving the problem so that he forms the necessary concepts?

Many studies in the psychology of learning have contributed to our understanding of these things. Cronbach[1] has summarized these with considerable insight. Applied to the methods which are our center of interest, the teaching of science, these studies may help us develop a scheme to illuminate the way of the teacher in the science classroom.

First of all, let us agree that learning is shown by a change in behavior, a new kind of response to a situation. Furthermore, if a change in behavior occurs, it is a result of some experience. Experiences which result in a change in behavior (learning) properly belong wherever teaching takes place; one of these places is the classroom.

To test learning, the teacher determines whether a given response occurs consistently in a given situation. The student learns, therefore, through responding to situations, as each situation is met, a response is tried, and the consequence of the response is evaluated. Every response then is a learning activity, since it teaches the learner whether his response produced the desired result or not.

Goals of the learner. Each learner has goals he wants to attain. These goals may be some object, a response from another person, or an internal feeling; they may be immediate, distant, or somewhere in between. A respectable grade, approval of parents and friends, the satisfaction of doing well, entrance in college—all are goals. Goals direct the energies of learning.

Readiness of the learner. A student's readiness consists of all the responses (knowledges, skills, attitudes), all the applications of his available concepts,

[1] L. J. Cronbach, *Educational Psychology*, Harcourt, Brace, N. Y., 1954. See especially pp. 45-66.

which he brings to a given task. Clearly this depends on his previous learning, his inherited capacity, and his maturity (physical, emotional, and mental). A student's readiness, briefly, indicates what he is ready for and what his limits are. High school teachers sometimes underestimate the readiness of students through undervaluing elementary and junior high school instruction. Or they may overestimate the amount of content recalled from previous learning. Be that as it may, students do come to high school with a certain amount of readiness; they have applied a good number of concepts in many areas (see Chapter 11, Science in the Elementary School, and Chapter 15, The Course in General Science).

The effective teacher determines by some form of pretesting the kinds of concepts his students have; in so doing he is partly determining their readiness. The more mature (ready) a person is, that is, the greater his understanding of the way the world works (a function of his concepts), the more likely he is to direct his efforts toward distant goals.

The situation. This consists of all that the learner can observe: people, objects, reactions, and symbols. The teacher's skill is shown in the way he sets up learning situations and the way he takes advantage of those which "just happen." Experience in one situation is a template for helping the learner respond effectively in similar ones. Effective science teaching consists in having experiences in search of meaning. Thus, since goals direct effort and readiness invites choice of goals, the learning situation should be set up to help the learner reach his goal.

For instance, having students learn how an automobile engine works with the engine before them is effective, but it is even more effective if the class recognizes the need to understand the engine because each student wants to drive a car (goal). It becomes still more effective when students plan the activities they want to undertake before they study the engine. In this way students assess their own readiness, bring to consciousness recalled knowledge and concepts, and define more clearly their individual goals.

Compare this with a teaching pattern in which the teacher proceeds from a diagram of an internal-combustion engine, demands a uniform level of understanding despite a wide variation in readiness, and does not make the reason for the study significant to the students. It is not surprising that the diagram and its labels are soon forgotten, and the real engine, problems of gasoline combustion and all, has to be learned anew, *and for the first time truly*, with the first engine failure.

Interpretation. Interpretation is a key process in concept formation. In interpreting, the learner selects; he directs attention to the significant parts of the situation, he relates to other experiences, he predicts the consequences of his responses.

A student confronted with the problem of determining whether the solution before him contains $NaBr$ or $NaNO_3$ may apply his knowledge of the $AgNO_3$ test for chlorides. He might, on the basis of his previous learning, interpret the situation as follows:

1. Silver, from silver nitrate, produces a precipitate with chlorides.

2. A chloride is a halogen.

3. A bromide is a halogen.

4. Since halogens behave similarly, it is reasonable to expect that $AgNO_3$ will produce a precipitate with a bromide.

5. He adds $AgNO_3$ and a precipitate forms.

Please note that the concepts in his mental equipment (halogens as a family, precipitation as a test, the chloride test) help him in further concept formation (a tentative test for a bromide). Note too that the concepts in his possession enable him to identify a problem—to seek it out. That is, if he had not mastered, to a certain extent, the prior concept, he could not conceivably have asked himself, "Will $AgNO_3$ precipitate a bromide?" Thus readiness helped direct his choice of the problem sought. In short, a concept is formed out of first seeking, then solving, problems. (Might not the latter be called concept seeking?)

Response. According to Cronbach[2] a response may be either "an action or some internal change that prepares the person for action." By this definition Cronbach includes as responses observable movements, spoken remarks, increases in internal tensions, and changes in physiology hidden from the observer. Provisional responses, or trial-and-error responses are made when the learner is not sure of his interpretation.

Consequence. In any event, there is either confirmation or contradiction of the interpretation. When the interpretation is confirmed, the learner is pleased and will in a similar situation repeat what he has learned; he will have added a new response to his repertoire. When, however, the prediction fails, the learner is "thwarted"[3] and may react in various ways. He may try different responses: the trial-and-error type or the type based on reason, an attempt to reinterpret the situation. Or he may give up, or act in a way which might be labeled misconduct (by changing his goals to those he believes he can attain, i.e., if not to be the best student, then at least the noisiest).

The elements of learning we have been discussing have clean-cut relevance to the way of the scientist (Section I). We have said that the central goal of the scientist is to develop the concepts which help him explain the world of experience. Each situation before him is interpreted in the light of the conceptual scheme he has previously developed. A phenomenon which does not fit the interpretation rarely completely thwarts the scientist. His adaptive behavior is to restate the situation as a problem, to define it clearly; he responds to this problem by designing a series of observations or experiments which will help him gradually reinterpret or modify the conceptual scheme. Those who behave this way bring to their problems a great deal of training, conditioning, self-discipline—readiness.

In terms then of the ways of the scientist (not the science student), problem

[2] *Op. cit.*, p. 50.

[3] Cronbach, *op. cit.* (Thwarting is made a separate category.)

solving is in a real sense concept seeking, done within the framework of a prior conceptual scheme. When considering problem solving schema it is an error to begin with the problem, for problem solving does not occur *de novo*. The scientist is not a newborn child; neither is the student. Problem solving to the scientist begins with a concept, and continues with that concept being applied to a new situation. A *problem* arises when that concept, expected to be applicable, is not applicable.

Now for the science student this is somewhat, but not wholly, different. It is at this point that science "problems" are significant, rote, or clearly fraudulent. Suppose the teacher does set up a problem: How is pure oxygen generally prepared? Suppose the student is already in possession of the concept. Is he still forced to go through with the procedure? Is he forced into nonproductive behavior, mere busywork?

Hence we submit that the problem-solving approach, if melded with what we know of the learning process, would be modified as follows:

1. A situation occurs. This may be planned by the teacher (what is this chemical solution?) or be an incident (what is the cause of this hailstorm?).
2. The readiness of the class is determined. What concepts do the students have? How varied is the readiness within the class? How closely is the situation identified with the experience of the students and their goals? This may be determined through discussion, through questions that require concepts to be used in making predictions.
3. The inadequacy of some of these predictions, which do not agree with the phenomena, then becomes the initial problem. Others may arise later.
4. The solutions to these problems are then sought through observing and experimenting.
5. The solutions lead to new interpretations, to new concepts, to the statement of new problems, to the solution of the new problems, and again to new concepts.
6. On the basis of these concepts new reading, new observing, new experimenting is done. This leads to further concepts, to further problem seeking, to further problem solving, and to new concept formation.

We submit then that the approach of the high school science teacher to constructive science teaching begins with students, who have various concepts in various stages of formation. However formed, correct or erroneous, the concepts exist or do not exist; at least the base for them exists if only because the students have lived before they enter the class. The facts are that they have also had specific science experience. The science teacher then proceeds somewhat as follows:

1. He has students who possess concepts about the way the world works.
2. His goal is to help his students understand better and with greater self assurance how the world works.
3. He sets up learning situations in which his students' readiness is tested.
4. If the concepts his students possess are not sufficient to interpret the

situation properly through correct responses, the class seeks to set up problems which will help them get the concepts by which they can respond correctly.

5. A correct response builds up, reaffirms the concept.

6. The teacher then develops new learning situations to build further concepts toward a conceptual scheme, through appropriate problem seeking and solving.

Problem solving is not then at the center of the method of the science teacher, concept forming is. Problem solving is a way of getting at concepts; it is the act of seeking them.

Eurekas—big and little

This section, and this title, are not entirely flights of fancy. We include them because we believe they will have value in the way teachers can help youngsters learn; this is the function of a text on methods.

Perhaps the story of Archimedes arising from his bathtub shouting "Eureka!" is a flight of fancy. But if he did not get his principle, his concept, in a "flash of insight," surely many others did.

We have all had the experience of getting an idea at odd moments—in the bathtub, taking a walk, shaving, reading. Suddenly there it is: Flash! Eureka! The concept which has been forming is attained. We shall denote by the word "Eureka" the flash of concept attainment, of discovery.

Of course, the cerebrum has been "mulling" over all the information fed to it by the information gathering devices of the human body: the ever-present stimuli to eyes, ears, nose, tactile senses, information from reading, from listening to others, from the questions asked in sequence, either by oneself or by others. "Thought," whatever it may be, may also be an unconscious process, going on without our "knowledge." Suddenly the thought processes, or the insights, or the responses to stimuli or questions "mesh," and—Eureka!

We are ashamed of the words we have used, meaningless words like "mesh" and "thought" and "knowledge," because these processes remain without explanations which satisfy us. Hence the Eureka, to label the sudden, intensive, unconsciously evoked flash of insight.

Young people, too, have Eurekas; in a program designed for the science prone we have noted this again and again.*

> One cannot work long with these youngsters [who do projects on their own] without wondering how they get their unusual ideas. One wonders whether they have a different way of thinking than others. Of one impression the writer is certain, these youngsters get a joy (one called it a "thrill of the brain") when they get an "idea" or make an "original discovery" (attain a concept). . . . These youngsters give the impression that they enjoy thinking. Their "Eureka" lights up their faces and seems to give them great satisfaction.

* P. F. Brandwein, *The Gifted Student As Future Scientist*, Harcourt, Brace, N. Y., 1955, pp. 58-60 (see also Chapter 9, The Science Prone).

> But is there any systematic approach that these youngsters have to a solution of their "intellectual" problems? How do they go about discovering "new" relationships [attaining concepts], doing what would ordinarily be called "discovery"?
>
> . It appears that when these youngsters first become interested in any problem area, there is just random *Exploration*. In this period of Exploration there is no focus, just a mental meandering. Then as part of this period of Exploration there seems to be a period of *Clarification*. This seems to be a period of focus when youngsters narrow down to a special activity, project, or problem.
>
> Once this *Clarification* occurs, it seems as if the youngsters begin a period of *Preparation*. They read, they explore techniques, they discuss problems with their advisers, they draw on previous experience. They work *consciously*, it appears, to solve the problem.
>
> But here is the nub of it. Rarely do they appear to get the "new idea," the "solution," the "approach to the solution" while they are *consciously* at work on the problem. Almost uniformly they seem to admit getting the *idea* in a "flash," a "flash of insight" [a Eureka], if you will. They get this flash while they are engaged in another activity, e.g., reading literature, listening to music, or walking—mainly walking—and when they are *not thinking*, or rather *not conscious of thinking of the problem* per se. This "flash" is what Wallas * calls *Illumination*. Wallas and Poincaré . . . put forth the notion that a period of *Incubation* is necessary before this "flash" or *Illumination*. So, too, it seems to us.
>
> During *Incubation*, the cerebrum seems to take over, seems to feed back the problem to itself as in a computer. Of all this the student seems not to be conscious. Then the "flash" . . . Then the solution of the problem, the approach, the new road, is laid bare.
>
> Then the youngster can barely wait to get to work, to embark on a period of *Verification*. Reading, experiment, planning, discussion, are borne lightly, for the "way" seems to be clear. The youngster often says, "Now I know where I'm going."
>
> These stages—Exploration, Clarification, Preparation, Incubation (unconscious), Illumination, and Verification—seem to be the vague yet perceptible stages through which these youngsters work.[3] The Incubation period, with its subsequent Illumination, seems to be especially characteristic. Is it different for scientists than for others? Is it characteristic of all thinking? Is there anything to it at all? Does this seem profitable for further investigation?
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> * Graham Wallas, *The Art of Thought*, Harcourt, Brace, N. Y., 1926. (*Brandwein's n.*)

The point is that concept attainment perhaps is not as often as we think the result of a conscious step-by-step process in which the concept yields to irresistible logic and investigation. We are inclined to the view (increasingly substantiated) that concepts are attained, more likely than not, as Eurekas.[4] Hence our distaste for the term "problem solving" as used to describe logical, step-by-step problem doing. For more often than not, problem solving, as char-

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[3] See Karl Duncker, *On Problem Solving*, Psychological Monographs, Vol. 58, No. 270, 1945, for many cases that follow this pattern.

[4] The reader will find these two books of increasing value in developing his own ideas of concept attainment:
J. S. Bruner, J. J. Goodnow, and G. A. Austin, *A Study of Thinking*, Wiley, N. Y., 1956.
G. Humphrey, *Thinking*, Wiley, N. Y., 1951.

acteristic of the scientist, is characterized by the Eureka. It is a flash, an act of creation. It is then, in science, subject to verification.

As Bertrand Russell wrote:[7] "Reason is a harmonizing, controlling force rather than a creative one. Even in the most purely logical realm, *it is insight that first arrives at what is new.*" Or, in our frame, the concept flashes into consciousness and then one may proceed to problem solving (or problem doing, as the case may be). *We are forced then in this section to sheer hypothesis, not yet verified but, we believe, eminently worthy of investigation.* Concept attainment cannot be controlled by the teacher, but the environment for concept attainment *can* be controlled (see Chapter 7, Winning Participation).

By this we mean that the teacher can so ordain his classroom (the climate of the classroom, Section I), the opportunities students will have (the pattern of classes, Chapter 3), and his manner (managing the class, Chapter 4) that students will have the material with which to form concepts and the desire to do so. But the concept is attained in a flash: the organism, Minerva-like, is full-formed. How it was put together remains to be discovered.

How often has a teacher labored vainly to plan a lesson in which the major idea comes in logical development at the end of the lesson? How often does this meticulously logical teacher (using lecture-demonstration) find a student who "has" the concept, who raises his hand frantically? How often has the lecturer built up his argument step by step only to find a flash of recognition on a student's face long before he has nailed his concept to the board? Concept formation can be planned for, through questions, problems, and experiences, but in our experience the moment of concept attainment cannot be controlled.

Of course, there are big Eurekas (Eurekas) and little Eurekas (eurekas). Archimedes had a tremendous Eureka; the boy who finds by himself that 2×2 and $2 + 2$ yield the same result has a little eureka, but a large-sized satisfaction. And little eurekas added one to the other patiently may even lead to a Eureka.

Lesson planning for concept formation

We might have headed this section "Planning for Concept Formation" or simply "Lesson Planning"; for teachers aim to involve their students in reflective thinking, leading to concept formation. Therefore, their major care when they drill or review or assign is to fix the concepts attained.

While the moment of the Eureka cannot be controlled, the pre-Eureka period (laying the groundwork) and the post-Eureka period (applying the Eureka) can be controlled. And the Eureka can be made up of eurekas; e.g.:

Lesson 1. A teacher desires to develop the concept of mechanical advantage (the simple machine). One day when the class meets, the students notice

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[7] *Mysticism and Logic*, Anchor Books, Doubleday, N. Y., 1957, p. 12.

a large cement block with a big eyelet at the top. Student after student tries to lift it to the two-foot height requested by the teacher without even budging it, until someone suggests a block and tackle (eureka). The block and tackle is set up; the block is lifted. How does it work? (assignment).

Lesson 2. Students read overnight and come into the laboratory to do various exercises (drill) with small pulleys. They test the notion of mechanical advantage (post-eureka).

Lesson 3. Next day they come into class; there is the big block again. The students are requested to lift the block again to a height of two feet; but this time no block and tackle is available. A student suggests a plank leaning on a chair, in other words, an inclined plane (eureka). This works. The teacher asks for similarities between the two machines. Possibly the law of machines is developed (Eureka). Or perhaps some subsidiary concept A is followed by another concept B, until the law of machines is formulated (eureka A + eureka B = Eureka).

Note that in this case three lessons were planned together to develop the concept sought. Concept formation usually does not occur in one lesson. Notice that one of the lessons (2) was mundane in that it was drill and more drill, getting familiar with the concept in one context, then extending it to a "new" setting.

On the other hand, a Eureka may be developed in one lesson. To illustrate:

A lesson. The class meets to find the teacher facing a two-foot slat of wood, with a small piece projecting over the edge of the desk. If he were to hit this projecting end with a hammer, the slat would fly out into the class. He asks the class how he can instead break it off. A student suggests that he place a weight on the body of the stick. Good. The teacher asks one of the bigger boys to stand on the desk on the body of the slat and proceeds to raise the hammer preparatory to striking the projecting bit. He then looks up at the boy and says, "I don't think you're heavy enough."

(This is a continued pre-Eureka situation: dramatization, suspense, puzzlement. *Surely the boy was heavy enough!*)

The teacher then obtains two sheets of a large newspaper and places them over the body of the slat. "Now," he says, "I have a heavy enough weight."

Suddenly (Eureka) a student raises his hand. "I know! There are 14.7 pounds of air per square inch pressing on the paper. That's very heavy." (He calculates the weight.) Another student raises his hand. "No," he says, "it's inertia." The students go home to read, to verify—some in post-Eureka (review), some in pre-Eureka (prior to understanding the concept).[a]

In short, the most skillful teachers we have observed plan assiduously a line of experience, experiments, demonstrations, questions which are pre-

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[a] This teacher never breaks the stick in class. He feels, and we agree, that students should be permitted to finish some things themselves, at home. In this way, we believe, they relish their Eurekas more than ever.

Eureka in nature. Their aim is to let the students experience the Eureka. Their assignments then are post Eureka, to extend, develop, and apply the concept Eureka born. In the next chapter when we speak of the special task of planning lessons in science, we shall deal with special methods useful in involving every student in concept formation, whether it be eureka or Eureka.

Now the reader may reject the notion of the eureka and Eureka as not useful to him. This is proper Pedagogy is not yet a science. But we believe that it is a useful concept to have as an aid in lesson planning, if the lesson has as its aim concept formation. We believe that this is indeed the aim of science teaching.[9]

A pattern for selecting learning situations

The central activity then of the science teacher, in his attempts to help children grow by developing concepts toward a satisfying interpretation of the real world, is to choose concepts on which to base learning situations. These in turn lead children to seek out problems and to solve them.

Productive science teaching depends on the choice of areas of human activity in which science has a part to play. The areas of human activity (atomic energy, reproduction, heating, etc.) furnish the area for concept-forming activity This depends on development of appropriate learning situations, which are a base for problem seeking activity. This leads to the identification of problems, planning of new situations, problem-solving activity, and concept formation And the cycle is repeated.

Which areas of human behavior a teacher or a school selects depends on the teacher, the community, the student population, and the administrator of the school. In largest part it depends on the teacher and his training. Margaret Mead[10] observed that a teacher expresses in his teaching (that is, in his choice of the ways the children in his class attain concepts) his own style of life. Although difficult to verify experimentally, this observation may help us fathom the friction which is evident in the relations of those who seek their inspiration primarily from subject matter and those who seek theirs from the problems of growing boys and girls (the areas of human behavior which draw upon concepts). There seems to be all the difference in the world between teaching the concepts of science as ends in themselves, and teaching them to help solve the problems of growing children.

In the subsequent chapters of the section, we shall undertake to look into the conditions of science teaching which will enable the science teacher to develop a pattern of teaching in which concept formation becomes an integral part of his style of life.

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[9] Bruner, Goodnow, and Austin, *op cit*, indicate that their studies of thinking lead them to divide thinkers (in the act of concept attainment) into "wholists" and "partists" Wholists seem to get the whole concept in a tremendous scanning process (Eureka); partists break up the process (eureka + eureka + eureka = Eureka).

[10] Margaret Mead, *The School in American Culture*, Harvard U. Press, Cambridge, 1951.

A short excursion into planning for concept formation

6-1. What is your major pattern of teaching? Or, if you are not yet teaching, what pattern do you think you will follow?

(a) Lecture (with demonstrations, perhaps)
(b) Discussion
(c) Laboratory
(d) All three, where most useful

Which of the first three lends itself best to concept attainment by the student?

6-2. We have suggested the patterns:

eureka a + eureka b + eureka $c \rightarrow$ Eureka
Eureka $\rightarrow$ eureka a + eureka b + eureka c

Do these seem to follow the two main branches of logic? Which one exemplifies the inductive approach? The deductive?

6-3. One of the most effective ways of helping youngsters develop skill in concept attainment is to make an opportunity available to them to do experiments on their own. You will find a treatment of this aspect of work throughout this book, particularly in Chapter 9, The Science Prone, and in Section V, Tools for the Science Teacher: The Project.

6-4. These will also be of exceeding use to you in developing your own approach to concept attainment:

Beveridge, W. I. B., *The Art of Scientific Investigation*, London: Heinemann, 1953.
Bridgman, P. W., *The Logic of Modern Physics*, N. Y.: Macmillan, 1927.
Wertheimer, M., *Productive Thinking*, N. Y.: Harper, 1945
Wightman, W. P. D., *Growth of Scientific Ideas*, New Haven: Yale U. Press, 1951.

CHAPTER 7

Patterns in teaching science:

Winning participation

A note at the beginning: The surgeon has his basic skill. The teacher has his. The surgeon needs to have the skills necessary for success in the operating room; the teacher needs to have the skills necessary for success in the classroom. The surgeon shows his skill in the "operation", the teacher shows his skill in the "lesson." How many of his students, captive in his class, can he involve in concept formation?

The lesson is not merely an exercise in applied psychology. It is people, teacher and student, *working together* toward a common goal in sensitive action traction, in concept forming. We urge the reader not to read this chapter without having read the preceding one on concept formation. these types of lessons are also discussed. Here we discuss the science lesson as a skilled "operation"; we dissect, as it were, the teacher's procedure.

For the teacher is known by the lessons he gives.

The purpose of what follows: It will be easy to misunderstand what follows in this chapter unless we state our purpose clearly. We cannot know what position our readers, the teachers who will use this book, will take in regard to their own teaching method; we cannot know precisely what pattern they will follow in the classroom—Mr. A.'s, Mr. M.'s, Mr. P.'s—or what element of each they will select and combine with their own ways so that their approach is an individual invention.

We do know, however, that it is the purpose of each teacher to teach the best way he can. One of the many elements of the successful teacher is his winning of the participation of as many students as possible, day in and day out.

Those teachers who plan with students enlist early their participation in planning the goals of the course, its major content, its topics, even ways of handling these topics (dis-

cussion, laboratory, lecture, film, report, panel, discussion, field trip, library lesson), and the many procedures which students may indeed plan and carry out with the teacher (see Section V, Tools for the Science Teacher).[1] Planning with students (as we have indicated in Mr. P.'s pattern, p. 78) brings out clearly the goals of the learner and focuses them. It enlists the learner; it makes him part and parcel of learning and, in that sense, part and parcel of teaching.

But the learner is still not the teacher; the community does not hold him responsible for achieving the goals of teaching. It is the teacher who is responsible for the procedures used. The teacher is in fact *the teacher* of any class for which he has responsibility. Where planning with students has failed, it has failed mainly because the teacher has permitted the students to take over his task, that of helping students win new concepts.

Finally, it is the teacher who must know the techniques of winning participation and helping students win concepts. His major skill is that of giving a lesson; in the lesson his knowledge of the psychology of learning (see Chapter 6, Winning the Concept) is clearly evident.

In our experience as teachers and supervisors of student teachers we have come to realize that the major fault of poor teachers is to be found in the lesson: they cannot, or do not, plan a lesson, and they cannot conduct a lesson to win participation. Somehow many of those who lecture consider the audience captive; many of those who plan with students resign to the students their role of teacher. The teacher should have his lesson well in hand, and when students are to conduct it, they must prepare for it even as he prepares for it, and with his help.

The remainder of this chapter is then given over to discussion of three major types of lessons:

1. Where the teacher plans the lesson with a clear objective. If he plans with students, this objective will have been stated by his students (with his participation). But it may be that this lesson is not susceptible to report or student discussion but must, because of special knowledge or skill, be planned and conducted by the teacher himself.

2. Where the teacher lectures, and is therefore clearly responsible.

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[1] It might be well if the reader were to turn to this section at the earliest opportunity in order to sample its content. Otherwise this chapter might leave him with the impression that giving lessons per se is the one way to win participation.

3. Where laboratory work is indicated and much preparation must be made, by both teacher and students.

The most effective teachers plan their work, plan with their students, and, in their daily well-planned work, work with students to achieve the agreed-upon (because jointly planned) goals of the year's work, the year's learning.

The pattern of the lesson

Before the beginning of the lesson

Every lesson, as an act of teaching, has a beginning. What isn't always considered is that there is also a beginning before the beginning: the lesson plan.

Planning as a must in science teaching. In few other areas of teaching is planning as essential as in science. Science teaching is not chalk-talk. It requires equipment—in biology, living things; in chemistry, solutions and apparatus of all sorts; in physics, calibrated equipment. The equipment must be prepared, and often repaired, before use. If equipment is to be used, it must be checked. Hence, if only because of the need to use equipment, the lesson must be planned.

Second, if a laboratory is to be planned, whether in general science, biology, chemistry, physics, or earth science, materials must be prepared.[2] Whether or not materials are necessary, the sequence of the development of concepts, the methods which will be used to help children in concept seeking, should be planned. The casual air of the skilled teacher is based on experience: experience in planning and experience in carrying out plans *en rapport* with the students.

Let us disclaim at once any notion that the lesson is to be rigidly planned. A lesson plan is a guide, not a pair of handcuffs; it must be flexible as human relations need to be.

The plan of a plan. A lesson is very much like the plot of a good short story. Whether it be by de Maupassant, Faulkner, or Maugham, the plan of the successful short story remains somewhat like this: BEGINNING, MIDDLE, END.

No matter what it is called—motivation, presentation, conclusion (summary or assignment)—there is still a beginning, a middle, and an end. To illustrate these three guideposts let us look at two plans taken from a teacher's notebook. Right now we are not concerned with analyzing these lessons in terms of concept formation; we are concerned mainly with their structure:

[2] In the volumes accompanying this text, Morholt, Brandwein, and Joseph, *A Sourcebook in the Biological Sciences*, and Joseph, Brandwein, and Morholt, *A Sourcebook in the Physical Sciences*, the organization of a squad whose duty is to prepare materials is fully discussed.

there is a *beginning* (which gains interest and states the aim of the lesson), a *middle* (which develops the aim), and an *end* (which gains the end desired and extends the lesson).

You will recall that in the preceding chapter we developed a structure for concept formation; this structure too had a *beginning* (problem seeking), a *middle* (problem solving), and an *end* (concept forming). But the moment when the Eureka occurs, when the concept is attained, cannot generally be controlled, that is, it cannot be organized to occur on a given time schedule. Nevertheless, we can try to isolate a time sequence of *pre-Eureka, Eureka,* and *post-Eureka.* The teacher is free to develop his own constructs about lesson planning. We cannot repeat too often that teaching is a personal invention. But it is helpful to distinguish between partially unconscious processes of concept formation and the conscious development of information which is sometimes the central task of a particular lesson (in the pre-Eureka stage, if you will).

A pre-Eureka lesson. This plan is the teacher's; it is not addressed to the students.

AIM OF THE TEACHER: How Is Blood Typed?
TO GAIN INTEREST: At a Civil Defense meeting it was suggested that each boy and girl carry an identification tag.

What should be on the identification tag? Response: name, blood type.
How many of you know your own blood type?

METHOD: (Discussion, demonstration, laboratory)

Key questions and activities	*Responses and activities*
TEACHERS	STUDENTS
What blood types are there?	Students suggest blood types (placed on board).
What is the principle of blood typing?	Students recognize principle.
Demonstrate blood typing.	Students type blood. Laboratory (12 minutes).

Conclusion: Summary of blood typing.

Applications and Assignments: By reading and remembering make a list of ways in which blood typing is important to us. (Whole blood transfusions, crime detection, etc.) What classifications other than Landsteiner's test are used to describe blood (at least ten other characteristics: Rh, m/n, etc.)? How many permutations and combinations would all these attributes have? On what basis have doctors suggested that the blood of each person who has ever lived was different from that of every other human? How might we find out what in the blood reacts to form the clumpings?

A modified laboratory approach.[3] This plan is addressed to the students; it might be duplicated and distributed to them, or used by the teacher as a guide.

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[3] This lesson plan devised by Bernard Udane, biology teacher at Forest Hills High School.

DETERMINING THE PRESENCE OF ASCORBIC ACID (VITAMIN C)

Introduction

A First we must get acquainted with a chemical called 2,6-dichlorophenol-indophenol (To simplify matters let us call it "indophenol" for short.) Pour about 10 drops of indophenol into a test tube and add it to some ascorbic acid (vitamin C) solution

1 What happened?

B. Prepare 4 test tubes as follows

#1	#2	#3	#4
indophenol	indophenol	ascorbic acid	dilute (1:10) ascorbic acid

With the aid of a medicine dropper, add the undiluted acid (test tube #3) to test tube #1 drop by drop Shake the test tube after each drop and count the drops necessary to bleach the indophenol

2 What results did you obtain?

In a similar manner, test the diluted ascorbic acid (test tube #4) against the indophenol in test tube #2.

3 What results did you obtain?

C Summary The greater the concentration of ascorbic acid, the —— the number of drops needed to bleach the indophenol

Problem A. Which of three juices (bottles A, B, C) contains the most ascorbic acid (vitamin C)?[4]

1 What did you do?

2 What results did you obtain?

3 What is your conclusion?

Problem B People sometimes add bicarbonate of soda when they cook their vegetables Use one of the juices to determine whether bicarbonate of soda has an effect on the ascorbic acid content.

1. What did you do?

2. What results did you obtain?

3. What is your conclusion?

Note, if you will, that these lessons are developing subsidiary ideas in a larger concept (see Chapter 6). The lesson on blood typing is only one in a series of lessons designed to develop, in this case, the concept "Genetic factors are inherited." Of course, the lesson could have been used in a planned pattern to develop another concept, e.g., "An antigen reacts with a specific antibody." Similarly the lesson on ascorbic acid detection could be placed in a pattern designed to develop the concept "Chemical substances regulate our body processes," or the concept of testing qualitatively and quantitatively.

These lessons are then parts of a lesson group structured toward the development of the concept the teacher has in mind (pre-Eurekas, see p 120). But there are other ways of planning activities, experiences, lessons, to develop a concept; these we developed in Chapter 4, Science Teachers (Mr. P.'s approach). Nevertheless, after we analyze the elements of various types of *lesson plan,* we shall return, for emphasis, to the question of organizing the lesson irrevocably toward concept development. We shall also concern ourselves with lessons

[4] Use fresh squeezed, canned or frozen juices: orange, lemon, grapefruit, apple, grape, pineapple.

which children and teacher plan cooperatively. (This is not to criticize the lessons above; they are models of their kind; within forty minutes, the boys and girls develop the ideas purposely planned ahead of time by the teacher.) Let us then dissect these lessons with the understanding of our purpose: to examine the anatomy of a lesson. Whether the lesson is planned by the teacher, by students, or jointly, it must still meet the realities of school life; *it must be an experience in search of meaning, but to be such an experience it must be planned.*

As we suggested in the last chapter, a major concept (Eureka) can be attained in one lesson; we described such a lesson. But 40 to 50 minutes does not usually permit this to be done fruitfully unless the concept is given ready-made, i.e., it is *told* to the students. This may be done through the lecture method, but then one must wonder whether the student has been robbed of the right of discovery.

For instance, let us suppose that we are interested in developing the concept of diffusion. It can be done in various ways. One way is this:

Perhaps the statement has been made that "seeing is believing."

At the beginning of the next lesson the teacher places a bottle of concentrated NH_4OH before the class and inverts an open test tube over the open bottle. Care has been taken to place a roll of wet filter paper on the inside of the tube.

The teacher asks: "What do you see?"

Students generally say: "Nothing."

(Unless they are sophisticated they will not "guess" that the fumes of NH_4OH are spiraling unseen upward in the tube.)

After establishing the point (with questioning) that nothing is seen, the teacher places a few drops of phenolphthalein on a fresh piece of filter paper and holds the paper over the mouth of the open NH_4OH bottle.[8] (All this is pre-Eureka.)

As the filter paper reddens, a student's hand shoots up (Eureka). He suggests placing a drop of phenolphthalein on the filter paper in the test tube; it will redden, he says, because the ammonia has diffused up (he may use another word).

Now all this could have been told the students in a few minutes; is it a waste of time to let them discover it?

A word of analysis: Compare the lessons on the preceding pages with the analysis of concept formation and the elements of the learning process discussed previously.

In each lesson, an attempt was made to determine the readiness *of the children (what concepts they already had) or to help them achieve readiness for the specifics to be studied. Where in each lesson was this readiness sought?*

In each lesson, an attempt was made to state the problem in relation to the

[8] This demonstration and others like it are fully described in the two accompanying volumes of this series.

concept formation desired This was done through a *selected* learning situation. *Where in each lesson was the "problem" clearly stated?*

In each lesson, activities were planned in which youngsters had an opportunity to apply the concept formed to a new situation. Where in each lesson was the new concept applied?

The beginning of the lesson

The lesson begins the moment students enter the classroom. Are they ready? Do they have the concepts needed? From this it can be assumed that any lesson begins the day before.

In most classrooms, the lesson ends with an assignment which is, in a sense, an extension of the lesson. Better than that, it is a "lesson" carried on at home. As such it should be planned with the students so they are aware of its purpose, so they seek out the appropriate concepts, so they have some clue as to the way it may be carried out.

If the teacher presents the assignment, then ample time should be given to make the assignment clear both in content and intent. Assignments are of different kinds and for different purposes. Most assignments are intended to ready the student for the next day's work. Yet other assignments, typically at the end of a unit, may properly extend and enrich the lesson without raising new questions.

In practice, homework can either precede or follow the relevant class session. When it follows the class discussion, we may consider the homework as intended to "fix" the lesson by additional experience not possible within the brief class session (the post Eureka period). Such "fixing" may elicit a self-evaluation by the student of how well he comprehends the new concepts. It may also provide additional practice and application in new circumstances, thereby clarifying the range and nature of the concept. It may, however, be the point of departure for individual extension of the lesson, in the form of special reading, special reports, or special observations not practical in school.

When homework precedes the lesson, it is intended to ready the student for the coming lesson in concept formation by supplying him with specific information and reminding him of pertinent experiences. Many teachers use homework for both purposes: reading in advance (pre-Eureka) and also practice on what was considered today (post-Eureka).

In the usual day's work, students will come in from a class or several classes in other subjects and have those subjects in mind. Or the brief period of badinage with friends may focus their thoughts elsewhere. Thus it is usually the practice of teachers to begin the lesson with a *learning situation* which focuses attention on the problem at hand. No matter what descriptive phrase is used, the teacher usually begins the lesson with an "approach" which, in the best practice, is interesting and attention holding, simple, direct, and on the student's level. If possible, it stems from the student's experience and has a clear relation to life and living. The learning situation is a pre-Eureka experience.

There is all the difference in the world between starting a lesson on static electricity by showing the class a rubber balloon "attached" to the wall and by showing them a statement on the blackboard, "Static Electricity." There is no reason why the beginning of the lesson should not be as interesting as possible.

An example:

One can begin a lesson on Bernoulli's principle with a question or a demonstration. The question "How many of you have been up in an airplane?" is better than the question "How does an airplane fly?" merely because the first draws upon a personal experience directly. A demonstration of the classic "ball in the funnel" or "card against the spool" will also stimulate discussion and analysis leading to the development of Bernoulli's principle. In our experience an opening demonstration is generally more effective than questions in focusing attention.

Do not assume, however, that demonstrations or "doing" must be used to open every class session. Some analyses can begin only with questions; for example:

What evidence is there that life exists on Mars?

What effect will atomic energy have on our lives?

How does smoking affect your health, your length of life?

Why can a normal child born today expect to live longer than a child born 100 years ago?

The most effective questions are those, related to the pupils' lives, which cause them to recall, weigh, and apply prior experience and knowledge. A *learning situation* occurs almost any time we focus the students' attention upon a problem which they identify, or challenge a concept the students adhere to. Such a situation, which is interesting and related to the pupils' lives or affects them in one way or another, will gain attention and will help give direction to the lesson much as a hypothesis gives direction to an investigation. Deliberate search for variety in these "opening moves" can be amusing to a teacher and can provide variations in his period-to-period or year-to-year teaching.

The middle of the lesson (techniques in questioning)

Once the lesson has begun (the learning situation is but a trigger) earnest analysis, earnest concept seeking through problem solving, begins. We repeat, whether the lesson is planned by the teacher, by students, or jointly, the lesson is an experience in search of meaning. The "middle" of the lesson is an investigation employing one or more learning techniques: discussion, laboratory work, film, reading, report, board work, and so on.

But first the topic problem, or center of concern, must be stated clearly, because everyone in the class should understand the purpose of the investigation about to ensue. This topic is usually called the "aim of the lesson," and much has been said of the way it should be derived.

It seems to us that when teacher and students plan the lesson, the aim is arrived at in discussion, jointly. But when the teacher takes the responsibility for the lesson, it is well that he state the aim clearly and place it on the board for all, especially the latecomers, to see.

Certainly the class must understand what the problem is. This may be checked and clarified by asking students, both bright and slower, to restate the aim in their own words. Although the aim may be stated in various ways, there seems to be a preference for stating it in the form of a question, possibly because "scientists ask questions." Psychologically or grammatically questions are probably more effective, for they imply confusion or doubt requiring clarification, whereas a statement can be simply accepted with no tension to the student. One must be careful, however, that the questions are not artificial or labored. For example:

"What is the laboratory preparation of oxygen?" is an artificial question. No one but a teacher would ask it, and the topic "Laboratory preparation of oxygen" is just as clear and even more natural. However, "In how many ways could we prepare oxygen?" hints of a multiplicity of procedures and initiates a search. "Why do we behave the way we do?" seems to be a valid question, a more interesting statement of the aim of a block of study than "Our behavior." We can only recommend that the aim be stated in as interesting a fashion as possible for the particular group of students at hand.

As we have noted, the middle of the lesson, the "meat" of it, may embody many learning techniques. No matter what the lesson, in science the major techniques deal with concept seeking through problem solving. Often the method of teaching involves questioning-demonstration observation, or the recounting of investigations with commentary (lecture method). In any event, in the middle of the lesson, following the initial, motivating learning situation, the teacher proceeds to elicit from or recall to the students a body of information and concepts, or to "tell" the students a selected amount of information.

One elicits by questioning, Socrates used this question-upon-question method very well, hence the term "Socratic method." Comenius implied this by his statement, "When the teacher teaches less, the learner learns more." Agassiz was a master of the art of questioning, exhorting his students to question nature as well. This method seems to be exceedingly successful for those who accept completely the philosophy behind it, namely, that the science classroom is a place to investigate by questioning, to question nature and to question people again and again. In any event, we believe that a Eureka occurs on the fertile ground of thought induced by pre-Eureka questions.

Therefore the techniques of questioning are basic to skillful teaching. A few practices arising out of experience and observation may be helpful here. Some very skillful teachers use these practices:

1. They often begin their questions with "What," "Why," "How," and "Where," rarely with the phrase "Could you tell us" or "Who will tell us."

The answer to the first set of questions is a sustained answer. A proper answer to the second set is "I can," or the act of raising a hand.

Also, if the question begins with the first set of words, it is usually brief and to the point. If possible, questions should be limited to less than 25 words, preferably about ten. Where possible, they should be limited to one sentence. For instance:

"Who will state Ohm's law?" (Answer: "I shall") is a poorer question than "What is the mathematical statement of Ohm's law?" And this, in turn, is a poorer question than "What do we learn from Ohm's law?"

"What are the functions of the kidneys?" is a better question than "Where are the kidneys located and what are their functions?" (Two questions really.)

"What was Niels Bohr's contribution to atomic theory?" is a better question than "What about Niels Bohr?" or "Who was Niels Bohr?" The former, at least, limits the boundary and puts all the students in the same ball park, if not on the same base.

We could multiply these examples, but it suffices to say that when you find a skillful teacher you find one skilled in questioning. And he doesn't have this technique at birth; he attains it only by diligent, uncompromising self-criticism and practice. Slowly but surely the skill grows.

2. Naturally, it isn't sufficient merely to ask questions; they must be asked in a logical sequence, to build towards the point of concept attainment. Specifically a lesson plan includes the key questions (see page 127). Note how, in the lesson plans cited, the different key questions cannot be answered unless the preceding one has been answered first. This is the clue to asking key questions: what information do we need before we can go on? The answer, in the lesson plan, depends upon the teacher's knowledge of the evidence and the logical web upon which the new concept (lesson aim) is based. Without such knowledge creative questions are unlikely.

3. Questions can serve varied purposes:

They may elicit known information to clarify a point, or elicit information known to only one or two pupils as a result of their special experience in school, at home, during a vacation, or on a trip.

They may encourage comparisons, the sorting and selection of information of relevance to the problem.

They may encourage analysis and the formation of new subgroups of attributes or reactions not previously recognized.

They may encourage generalizations, or "*hypothesis hazarding.*"

They may elicit hypothesis appraisal by testing the degree to which the hypothesis is consistent with the data it presumably describes, or by exploring whether the hypothesis suggests or accounts for additional facts or reactions not among the original data used.

4. The questions asked by skillful teachers are varied in their difficulty. Some are directed at very bright students; others, at slower students. Some are

on the levels of abstraction, others ask for simple recall or simple reasoning. For instance, in a lesson in chemistry (on catalysts) the following questions are among those which were asked in sequence during the lesson.

How is oxygen prepared from $KClO_3$? (Simple recall, written on the board for ready reference)

Which substance among these is the catalyst? (Plainly, simple recall.)

What is the function of the catalyst? (A bit abstract, calling upon reading)

How would you demonstrate by experiment this function of the catalyst? (Aimed at the bright, calling for reflective thinking, etc.)

5. The skillful teacher not only accepts responses to his questions from volunteers, but calls for participation by "auditors" (reluctant participants in audible response) as well. Thus, Joe (who is shy) has a question directed at him now and then. And Frank (who is constantly raising his hand) is often ignored, but occasionally gets a difficult question to challenge him.

6. The skillful teacher does not answer questions directed at him by students. He throws them back to the class. If the answer to the question is not necessary to the sequence of the lesson, if it is a digression, he may ask a student to volunteer to investigate the problem and report to the class. If the information is necessary to the sequence of the lesson, then the teacher who is addicted to questioning will probably divide the question into subsidiary ones and elicit the responses from the students. This presupposes some information residing in the class; "no response" may be the basis for the next assignment (see The End of the Lesson). These, then, in general, are verbal devices used by skillful teachers in eliciting information by means of questions.

7. Skillful teachers have the notion that when a youngster offers a response he generally does so because he sincerely believes that it is *correct*. If he *knew* it to be inaccurate, he would not offer it. Therefore, when a youngster gives an inaccurate response, they question him with the purpose of having him appraise his information or revise his thinking (his conceptual scheme). Thus one not only questions the class, one returns questions (asked by a student) to the class; one questions youngsters and one turns an inaccurate response into an accurate one by further questioning.

8. Skillful teachers also question youngsters who give accurate responses. They milk the answer dry of meaning, as it were, and often the youngster is full of wonder as his original response grows in meaning.

9. Finally, skillful teachers apparently direct their questions at the entire class, then call the name of the youngster they might want to respond to it, rather than the reverse. For example: "John, why is it colder in the winter than in the summer?" is a question which catches John's attention: the rest of the class may relax while John copes with it. Whereas wording the question: "Why is it colder in the winter than in the summer? (pause) John?" holds the class, encourages each student to think reflectively about the prob-

lem before a particular pupil is called. Of course, there may be a volunteer, and then the teacher may still disregard the volunteer and call upon John.

The end of the lesson

It seems to us that the *end* of the day's lesson should not consist simply of the assignment. It should include some evidence that the purpose of the lesson has been accomplished. That is, the problem has been solved; the concept sought has been formed.

In most cases this evidence is sought by questioning—searching questioning. Furthermore, at the end of the lesson especially, this questioning is usually directed at the slower students. If they understand the concept taught, can state it, and apply it to situations in their experience, then it may be assumed that the others in the class understand as well. Time is given at the end of the lesson for all students to ask questions which arise out of the "new" questions of application, or significance, that the teacher asks.

In general, what the teacher tries to do at the end of a lesson is to give a "new view" of the concept rather than a "review." For instance in dealing with, for example, the concept of "cells," a teacher might pose a "problem" as the new view, a research problem, as it were. "Suppose someone reported a species of animal never before discovered; what could you say about the inner structure of the animal you have not seen?" Now the students should agree that the internal structure is probably cellular. They should also be able to indicate the breakdown of the organism's internal structure from organ systems to cells. In short, they have applied to a new situation the information they have learned. In a lesson on simple machines, the new view might well be the analysis of a demonstration pulley system. In a lesson on the properties of sodium, the new view might be to ask the class to predict the properties of a similar metal, such as potassium.

In any event, at the end of the lesson the teacher also tests himself. Has he achieved the purpose of his lesson; have the students learned? Can they now organize data or make predictions not possible before this lesson?

Even a short quiz is useful. This does not mean that the teacher must wait until the end of the lesson to appraise the efficacy of his approach or his teaching. In the questioning-discussion approach, the teacher is constantly testing his teaching because he is constantly getting responses. This is also true of the assignment-recitation approach. It is less true of the lecture approach. In many cases the lecturer does not know whether he has achieved his aim until the day of the test. Here then is one of the major disadvantages of the lecture approach. If carried to the extreme, the lecturer does not have the opportunity to test his daily achievement through the daily responses of the learner. He usually cannot modify the mode of concept telling until the first written examination (and perhaps not even then). It is clear then that where the lecture approach is used, sufficient time should be taken at the

end of the hour to determine whether the concepts have been "taught" and "learned."

The lesson can be extended by means of the assignment. In the assignment, concepts formed are applied through additional problem solving. If the assignment is in preparation for the coming day's work, which is then to be merely a recitation of that assignment, much is lost. If the lesson is an enriched development of the previous day's assignment, much is gained.

On the other hand, an assignment can be used to extend the day's lesson so that the student not only reviews the day's work but also adds depth to the concept studied.

For instance, a lesson on cells can be extended by reading the historical development of the concept of cell, or the lives of Schleiden and Schwann, or of Dutrochet. A lesson on pulleys (in the pattern of developing the concept of mechanical advantage) can be extended by asking students to discover a use of pulleys (window shade, etc.) and to do some problems related to the window shade. An assignment is valuable when it is made part and parcel of the method of intelligence, that is, when it furnishes an opportunity for investigation and reflective thinking about important problems, perhaps related to the students' lives.

Summary—the lesson

Apparently we have been dealing with an administrative *coup d'état.* A teacher meets his class for an hour or so. What he does in that hour is called a *lesson* (for the curricular frameworks of lessons, see Section III). Skillful teachers, observation shows, apply the psychology of learning to make the lesson as interesting and as significant as possible. They build toward a Eureka.

Generally, skillful teachers *begin with a learning situation* which captures interest because the concepts to be attained have meaning to students. They *continue to develop the lesson* by a selected procedure which evolves the concept lying at the heart of the lesson. They *end by demonstrating* to themselves and to the pupils *that they have achieved the aim of the lesson;* the concept has been taught and the concept has been learned. Then they extend the lesson outside the school day in either a "new view" of the concept taught or a preparation for the following day.

Patterns in lessons

The lecture as a lesson

We have discussed, in the past pages, a lesson as a way of winning the participation of students in concept formation. The lecture method does not attempt to win overt participation; indeed its single, most significant failure,

in our minds, is that the lecturer usually cannot know whether his audience is participating unless he has "yea-sayers" and "nay-sayers" in his class. Too many students have learned how to keep their eyes fixed on the lecturer and their minds elsewhere. (Unless, of course, the lecturer is a master.)

The lecture method is a major form of instruction; even reports, films, filmstrips, and such are really "lecturing." Most college instruction is by the lecture method. One of the authors has visited some 70 high schools throughout the United States, and in approximately 20 of these the lecture method was used. In a questionnaire study of the methods used by some 200 teachers representing most states in the country, 62 (about 30%) stated that they used the lecture method almost entirely in the majority of their classes.

No broad statements can be made about the lecture method, because it is even more highly characteristic of the individual teacher than is the discussion method. Good lecturers are rare and those who can hold the complete attention of a group of young adolescents for a class hour are very rare. For the younger the class, the shorter appears to be the attention span. The audience is captive but not necessarily captivated.

The most skillful lecturers we have observed can be described, in general, by the following portrait:

1. He has a strong personality; by his presence he commands attention.

2. His use of voice is compelling; there are nuances, there are changes in tempo, in amplitude, and in pitch to assure emphasis of important points. His is not a monotone monologue, but a "rich" modulation. The voice is clear, and clearly heard in every corner.

3. He moves about to be clearly visible to all and to compel attention. (To remain seated is to invite inattention.)*

4. Generally, he develops important concepts through differing contexts. Each major point is clearly an entity, thereafter the scene changes for the next activity.

5. He organizes the sequence of concepts presented on the board, sometimes using colored chalk, to encourage note-taking. Then at the end of the lecture the board shows a complete outline of the concepts presented.

6. He organizes the lecture clearly into a beginning (motivation), a middle, and an end (usually a summary).

7. He asks rhetorical questions to emphasize sequential points in the logical development of a concept by stimulating nonvocal answers in each member of the audience.

8. He spends the early days of the term (particularly with young students) in teaching the class how to take notes, and discusses good study habits. Notes are often handed in and discussed the next day in class.

9. In order to clarify the concepts presented, he devotes either the first

* One lecturer noted that three elements which compel attention are sound, movement, and color.

minutes of the lesson to questions about the previous day's lecture, or the end of the hour to questions about that day's lecture.

10. He assigns material at the end of the lecture to be covered in the lecture on the following day Thus youngsters are "readied" for the "telling" by reading.

11. He is generally flexible He will stop in the middle of a lecture when he notes puzzlement on young faces, and revert to question discussion technique until the difficulty is clarified.

12 He shows a sense of humor consonant with the tone of the lesson.

The recitation as a lesson

The lecture and discussion are two teaching techniques; the predominant technique seems to be the *recitation* approach, a sort of combination of these. A definite assignment is given ("pages 103 to 111, and the questions at the end of the chapter") at the end of the lesson. The next day is spent in clarifying the assignment by a hybrid discussion telling technique. The teacher asks questions calling upon members of the class. When the understanding of a concept seems doubtful, the teacher again "tells" the class with further illustrations Or as most teachers would prefer to say, the teacher *explains.* The varying amounts of "explaining" and "discussion" seem to depend on how well the class "knows" the body of subject matter to be covered.

A word of analysis: Where the lecture method and explanation discussion seem to be dominant, the school (or the teacher) seems to be concerned mainly with subject matter, and less with personal social growth and attitudes. Where the questioning investigative approach seems to be dominant, the school (or the teacher) seems to be concerned with pupil growth, with attitudes as well as with subject matter. This is not to say that the questioning-investigative teacher does not teach subject matter well; indeed his method may be designed to get youngsters to learn independently and thereby grow in scholarship as well as independence in planning one's work. The lecturer, on the other hand, gives the student all the eurekas and Eurekas; he covers material; he does not, unless he plans carefully, uncover it for analysis.

The laboratory exercise as a lesson

Now we should analyze another type of lesson which is characteristic of our way of teaching: the so called laboratory lesson or exercise. Here the student works with his hands as well as his brain, while the telling by the teacher is at a minimum In this type of lesson there is still the beginning, the middle, and the end.

Generally speaking, however, the laboratory exercise as it has developed is even more binding than a lecture. The student is usually told what to do

step by step, by a workbook or laboratory manual. Some teachers go so far as to call the workbook a "cookbook."[7]

In our experience, students find laboratory work "fun" even when rigid direction robs them of the experience of discovery. Probably the laboratory is a welcome change from the cramping of the regular classroom; and young people like to "mess around."

Now laboratories should be distinguished from shops. The shop may have the equipment of the laboratory, but not its intellectual climate; for in the laboratory we usually *investigate*, whereas in shops we usually *make* things. When the laboratory becomes a place for making things, e.g., preparing oxygen or making a magnet, it is being used more as a shop than a laboratory. Where investigations are carried out, even cookbook topics, e.g., examining a *Paramecium* to determine its structure, or determining the inverse-square relationship between distance and the brightness of a light, we approach the intent of the scientist's laboratory, but we are still far away from it.

Most teachers are agreed that these "cookbook" experiments have their place. They defend the workbook by indicating that it is a means by which the cultural heritage (in this case the work of scientists in the past) is transmitted to the new generation.

But the laboratory need not be a place where ingenuity is rarely required. Let us examine a few types of laboratory lessons, from the strictly cookbook type to one where the student brings all his concepts into play in Eureka activity.

Type A—little latitude. In this type, although a certain latitude is permitted, the student cannot squirm out of the iron bands of the questions. (It is used mainly in pre-Eureka.) It is very useful for dissections, learning how to use a microscope, etc.; in short, for development of skills.

MEASURING SPECIFIC HEAT

We are going to calculate the specific heat of a metal by heating it to a convenient temperature (100° C) and then placing it in a calorimeter containing some water at room temperature. The total heat given off by the hot metal will be known if we calculate the heat absorbed by the water (from $m\Delta T$). Consequently, the amount of heat lost by *each gram* of the metal as it cools through each degree (its specific heat) can be calculated.

Apparatus

Boiler, Bunsen burner, thermometer, calorimeter, beam balance and weights, block of metal such as aluminum, iron, brass, or lead.

Procedure

1. Heat half a boiler of water, noting at what temperature it boils.

2. Weigh your sample of metal and suspend it by a string in the boiling water. Its weight is ——. Allow it to remain there for several minutes until the

[7] In a Midwestern state a teacher taught chemistry by using the workbook as a "contract." When they finished all the "exercises" students could go on to their own projects.

metal reaches the same temperature as the water. (This is the starting temperature for the metal.)

3 Meanwhile weigh the calorimeter can. Its weight is ——.

4 Then put about 200 grams of cool tap water in the can. The weight of the water plus can is —— The weight of the water alone is ——.

5 Take the temperature of this water. (This is the starting temperature of the water and calorimeter can.)

6 As quickly as possible transfer the hot metal to the calorimeter can of water and stir the water constantly, noting the highest temperature to which the water rises (This is the final temperature for both metal and water.)

Record your observations and data in the accompanying table.

	Water	*Calorimeter can (made of ...)*	*Metal (...)*
Observations			
Mass			
Specific heat (S)			x
Final temperature			
Starting temperature			
Calculations			
Temperature change (ΔT)			
Heat gained ($m\Delta TS$)	h = ——	h' = ——	no entry
Heat lost (H')	no entry	no entry	H' = —— x

Total heat gained $H = h + h' =$ ________

Total heat lost $H' =$ ________x.

According to the law of heat exchange, how does H compare with H'? ______ Write the equation showing this relation between H and H' and solve for the specific heat of the metal x: ________________________.

Note that students do learn something; they confirm the text; they learn to do a problem, not to solve it.

Type B—some latitude. Some teachers prepare their own work sheets. After the workbook activity, considered an "exercise," they introduce a kind of activity which involves some degree of originality. Such an activity follows.[8]

Note that it involves the testing of various solutions for conductivity. Then in the section, Going Further, there is an opportunity for students to develop their own procedures and make their own observations. A kind of originality is being stimulated. (Before the exercise, students are shown how to test for conductivity using a conductivity apparatus.)

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[8] Personal communication from laboratory directions developed by Carl Spear. New Rochelle High School, New Rochelle, N. Y.

Solutions to be tested	Brightness	Kind of substance	Equations showing formation of ions (if any)
	BRT DIM NONE		
dry salt			
pure water			
sodium chloride sol'n			
glacial acetic acid			
acetic acid sol'n			
barium chloride sol'n			
copper sulfate sol'n			
potassium nitrate sol'n			
hydrochloric acid			
HCl gas in water			
HCl gas in benzene			
nitric acid sol'n			
sulfuric acid sol'n			
sodium hydroxide sol'n			
potassium hydroxide sol'n			
calcium hydroxide sat'd			
ammonium hydroxide sol'n			
alcohol sol'n			
sugar sol'n			
acetone sol'n			

Definition of an electrolyte: a solution which conducts an electric current.

Important considerations

1. What kinds of substances are electrolytes?
2. List here the acids which have a high degree of ionization (strong acids).
3. List here the bases which have a high degree of ionization (strong bases).

(This information is important, because it is the basis for a later experiment.)

Going further

In the experiment on ions, you measured the strength of acids (or degree of ionization) by conductivity. You can also measure the degree of ionization by measuring the rate at which a metal dissolves in various acids. Make dilute solutions of some acids as you did in section 1 of this experiment. Have ready small strips of magnesium ribbon 1 cm long. Check the action of the acid on the metal.

Type C—some latitude, initial direction from teacher. A worksheet on an experiment.

What is a controlled experiment? Is moisture necessary in order for mold to grow on bread? Set up an experiment with a *control* to help answer the question about mold. Here are some suggestions. My procedure: (a) Expose a slice of bread to the air until the bread is dry. (b) Break the bread into two pieces. (c) Moisten one piece; leave one piece dry. (d) ________________________________
________________ (e) ________________________________
My observations of the results: ________________________________
____
My conclusion: ________________________________

Type D—considerable latitude, "experiment" suggestion from teacher. The student has an opportunity for a Eureka.

> *Does black cloth or white cloth absorb more heat from the sun?* In order to answer this question, plan an experiment to get direct evidence about the ability of black and of white cloth to absorb heat. Outline your procedure, list the facts obtained, and state your conclusion.
> Purpose of my experiment ______
> Plan of my experiment (illustrate this in the space below).
>
> Facts obtained ______
> My conclusion ______
> How do you apply your conclusion to your selection of clothing for winter and summer wear? ______
> ______

Type E—considerable latitude, bare suggestion from teacher

> *Do protozoa select their food?* Does a protozoon take in all substances in the water or does it select special materials as food? Devise a simple experiment to find the answer, get your teacher's approval before starting. Then carry out your experiment.

Type F—jointly planned. A "problem occurs to the class" and the teacher and students plan together; several days are used in working towards the concept (see p. 44, Chapter 2, Teaching the Ways of the Scientist).

Type G—student-initiated. The student plans the work independently and works day in, day out, in the laboratory (see pp. 38-40; also p. 178).

Probably all variations of laboratory lessons, from Type A to Type G, are attempted by the most skillful teachers. No doubt it is reasonable to question a course whose laboratory procedures are of Type A only.

Whether or not we approve or disapprove of workbooks, the fact remains that they are used throughout the nation. And as we see it, their main function is to give youngsters a chance to *do*, to experience at first hand, as well as to *read*, the cultural heritage of science.

There is no evidence that youngsters learn better through laboratory work than through lecture demonstration or demonstration-discussion. As a matter of fact, the weight of the evidence (necessarily but unfortunately based mainly on paper and pencil tests[9]) is on the side of demonstration-discussion and lecture-demonstration. But this sort of "experiment" (if indeed demonstrations are acceptable as experiments) neglects two phases of laboratory work.

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[9] See, for example, Ralph E. Horton, *Measurable Outcomes of Individual Laboratory Work in High School Chemistry*, Contributions to Education No. 303, Bureau of Publications, Teachers College, Columbia University, N. Y., 1928, and Haym Kruglak, *American Journal of Physics*, *22*, 442, 452, 1954, and *23*, 83, 1955. See also our Chapters 13, The Course in Chemistry, and 14, The Course in Physics.

1. *Skills*—e.g., responsible use of microscope, Bunsen burner, graduate cylinder, balance, slide rule, and the like—*are taught not by lecture demonstration but by doing in the laboratory.*

2. While information which is part of the history of science (Oersted's experiment, oxidation, structure of the amoeba) can be taught (in the sense that students can recall it) as well by lecture and discussion-demonstration procedures as by repetition in the laboratory, *most youngsters enjoy working in the laboratory.* Apparently the psychological framework of initiative and responsibility provided by the laboratory is appealing to them. Unfortunately too many of them leave high school science with the notion of the laboratory as a shop, rather than as a place for investigation. But even when used as a shop, the laboratory is often a welcome diversion from the chalk-talk, or lecture, type of science teaching.

In the volumes accompanying this text, *A Sourcebook for the Biological Sciences* and *A Sourcebook for the Physical Sciences,* the teacher will find a rather complete description of laboratory and demonstration practices as well as those useful in conducting field trips. The tables of contents for these volumes are given at the beginning of this one.

Summary 2: the lesson

We have discussed in this chapter practices in winning participation by students in one's class. We have described ways of winning participation in concept formation mainly by the method of questioning. We have indicated the strengths and limitations of the lecture approach and we have delved into the "laboratory exercise."

The teacher is known by the lessons he gives. He is also known by his success in dealing with students who find science difficult and those who find the course so easy as to be boring. This means that the lessons of the skillful teacher cannot be standardized; they must be as varied as the students in the classes he teaches. An almost impossible task, it is approached daily; sometimes one carries it off.

An excursion into methods of winning participation of one's students in learning

7-1. As we have said, this chapter is limited to the three major types of lessons: the discussion (with and without demonstrations), the lecture, and the laboratory. Nevertheless, the teacher does plan textbook lessons, film lessons, field trips, projects, reports, and so forth. All these, and others, are variations of the three types we mentioned; e.g., the field trip is a type of

"laboratory lesson." You may want to turn now to what we consider "tools" of the teacher, Section V of this book which includes among other tools:

Textbooks
Films and filmstrips
Demonstrations
Projects

7-2. Perhaps you would like to analyze the "slightly used lesson plan" which follows

OBJECTIVES

1. To realize that different factors may be responsible for the same effect—differences in flame color may be produced by temperature differences or by different substances glowing or burning.

2. To show that some substances may be identified by their flame color and that simple tests are not always conclusive, but that refinements narrow the possibilities.

3. To suggest that there are several related but different means of producing light, of which one of the earliest was the arc.

4. To show that the arc light completes its circuit across a gap by means of an *electric discharge*—a distinction from *electrical conduction* through a wire.

PREVIOUS DAY'S LESSON: Flame and diagram, burned carbon.

OUTLINE

1 Review characteristics of flames, reasons for variety of colors

2 Carbon in chimneys.

3. Study Bunsen burner flame, closed and open, compare.

4. Add chemicals to flame, modify reasons for color differenees Note color of *electric* bell *spark*.

5. Means of producing light: sun, lamp bulb (hot wire), photoflash. Metal will burn. magnesium, heat, copper wire, iron wire.

6 Arc light, brief history, complete circuit, construction, 200 amps × 30 volts equals 6,000 watts Vaporization of carbon rods, adjust. Welding, spark plugs burn back, movie projectors, searchlights.

(a) Could you, with a few hours for preparation, teach from this lesson plan?

(b) Do you know what pervasive and what limited objectives were sought?

(c) How was the attention of the class focused on the lesson?

(d) What effort was made to discover what the students already knew about the subject?

(e) What kind of activity would you expect the students to do?

(f) What summary was made? By whom?

(g) What might have been done at home by the students *before* this lesson was *given?*

(h) What assignment was given?

(i) What would you expect to find occurring in this class the next day?

(j) What aspects of the lesson seem especially commendable?

(k) How would you restate the lesson plan in a more useful manner?

(l) What behavioral objectives might be sought?

7-3. Is there a special problem in planning the lesson for the "reluctant student," the "slow learner," the "under achiever"? We prefer to call these the "science shy" for the reasons we develop in the next chapter (Chapter 8). The types of lessons to be given, and the methods of winning participation need to be modified when one deals with students shy of certain qualities needed for success in science. Perhaps this chapter should claim your attention next.

7-4. Is there a similar problem with the "rapid learners," the "gifted students"? Their intellectual needs are different from those of the students mentioned above. And the methods of winning participation need also to be modified. Perhaps Chapter 9, The Science Prone, has priority for you.

7-5. Nevertheless, a plan of a lesson is a tactic in a master plan. A plan should succeed and should have value. We believe that most teachers' tactics and strategy are rarely challenged. Do you agree? Have your plans and methods ever been challenged as directly as General McClellan's were by Abraham Lincoln?

EXECUTIVE MANSION, WASHINGTON, D. C.
February 3, 1862

Major General McClellan:

My dear Sir:

You and I have distinct and different plans for a movement of the Army of the Potomac—yours to be down the Chesapeake, up the Rappahanock to Urbana, and across land to the terminus of the railroad on the York River; mine to move directly to a point on the railroad southwest of Manassas.

If you will give me satisfactory answers to the following questions, I shall gladly yield my plans to yours

FIRST. Does not your plan involve a greatly larger expenditure of time and money than mine?

SECOND. Wherein is a victory more certain by your plan than mine?

THIRD. Wherein is a victory more valuable by your plan than mine?

FOURTH. In fact, would it not be less valuable in this, that it would break no great line of the enemy's communications, while mine would?

FIFTH. In case of disaster, would not a retreat be more difficult by your plan than mine?

Yours truly,
Abraham Lincoln

CHAPTER 8

Patterns in teaching science:

The science shy

A note at the beginning: In a summary of a study of practices used with slow and rapid learners in 678 junior and senior high schools,[1] we read "The main conclusion, resulting from this study of provisions and procedures employed by science teachers considered to be extremely effective with slow learners and rapid learners, is that these teachers use largely the same general provisions and procedures with both groups of pupils. However, science teachers of rapid learners use the provisions and procedures somewhat more extensively and in a few cases much more extensively."

Is it strange that the "same general provisions and procedures" should be used largely with both types of students? Or is it sound? Let us see.

The science-shy student—his nature

Why is it that not all students do well in science? A fable told by Harold Hand is in order: [2]

> Sam Sparrow and Sid Swallow * were both below the legal school leaving age, and were both enrolled in the same course in flying. To simplify matters, let us assume that the sole purpose of this course was to teach the pupils to fly as swiftly as possible. When the course began, Sam could fly twenty miles per hour, but Sid could do forty. Both were conscientious pupils, and both studied as hard as they could. Each learned everything that it was possible for him to learn in the course. But because nature had endowed them differently, Sam Sparrow could fly only forty miles per hour when he finished the course, whereas Sid Swallow managed fifty miles per hour on his final examination.
>
> * Sparrows and swallows, of course, are not the same species of bird, we do not mean to imply that our children belong to two different species, but simply that they differ greatly in their capacities to learn.

[1] *Teaching Rapid and Slow Learners in the High School*, Office of Education Bulletin No. 5, U. S. Government Printing Office, Washington, D. C., 1954.

[2] Harold Hand, *Principles of Public Secondary Education*, Harcourt, Brace, N. Y., 1957, pp. 234-38.

For the reasons implied in this fable, we are not ready to use the term "slow learner" as specifically applied to learning in science. In our observation and experience, poor achievement in science, as in any other area, is due to many factors, some of which are described here. It must be remembered that none of them operate in isolation.

His intelligence (as measured by intelligence tests). *All other things being equal* (they never are, of course, but dealing with factors one at a time is a useful means of analysis), the achievement of a student in the science courses now given is generally a function of his intelligence as described by his I.Q. score. Present science courses stress the same qualities as do intelligence tests: ability to retain and organize information, high verbal and mathematical facility, fairly quick reaction time, and other similar properties relating to success in paper-and-pencil testing activity.

Obviously, students with an I.Q. score of 80 will not achieve the same score on test items as will students with an I.Q. score of 120. When students of I.Q. scores 80 and 120 are placed in the same class and subjected to the same standards (expected to attain the same goals to the same degree), then clearly the students with I.Q. scores of 80 will be "slow learners."

This may not be true of other activities, however; compare their success in areas other than strictly intellectual endeavor: running the 100-yard dash, plowing a field of 10 acres (with a tractor), organizing a party, playing the saxophone, or fixing an internal-combustion engine or a motor.

His interest. *All other things being equal,* the extent to which the individual student is interested in learning the kind of science offered will determine the extent to which he achieves success in science. Students who are waiting to reach the required age in order to enlist in the Marines, or who come from families where "book knowledge" is not esteemed, or to whom high school is merely a place to mark time while one complies with the compulsory education law, will generally not reach the level of achievement expected. Nevertheless, such students can be taught, and can learn, if the teaching nurtures the climate of science teaching developed in Section I, is based on what is known of concept formation (learning theory) as developed in Chapter 6, and approaches class management from the viewpoint of democratic planning (Chapter 4). Interest, or motivation, as an aspect of learning, is capitalized on to a great extent in such an environment. If a student *wants* something and his course helps him *get* it, he will be more likely to learn to the best of his capacity.

The nature of the course. *All other things being equal,* the nature of the course determines the extent to which students will succeed in it. This is a matter of common experience. Certain students who get grades of A (90% or above) in general science and biology may achieve B's or C's in physics. Physics, as presently given, requires a higher degree of skill in mathematics than do biology and general science. Since some students have high verbal skills but do not possess comparable mathematical skills, they may

do well in the descriptive aspects of science but not so well in the quantitative.

This is not to imply that all biology and general science courses are of uniform difficulty for all students of equal I.Q. or equal motivation (if such "equality" is conceivable). A course in biology which emphasizes the minutia of classification, the fine points of anatomy, or the mass of detail of the botany and zoology characteristic of the 1900's (including detailed drawings of objects, studies under the microscope, and the use of dissecting equipment) may not be as interesting as one which deals with aspects important to the student in his daily life, such as nutrition, disease, body physiology, human heredity and reproduction. Each student's devotion to study and application will be different in such courses because each student is a different, complex personality.

His prior preparation. *All other things being equal,* prior preparation (schooling) of a student will affect his success in a course. At Forest Hills High School, N. Y., the test scores of students in general science (even when equated for I.Q. score, reading score, and mathematics score) varied directly with their previous training in science.[3] Students who came from elementary schools in which science work was practically nonexistent or was of the "nature-study" type, or from junior high schools in which science was offered only one period per week in the seventh and eighth grades, achieved on standardized general science tests scores as much as 25 points lower than those who had rich science work in the years preceding their general science course.

Et cetera. We have commented upon only four factors out of the innumerable ones which affect learning in science. The prestige of science in the socio-economic group from which the student comes, the nature of the preparation of the teacher, the guidance program of the school, the destination of the student, the nature and extent of teaching materials, the extent of the remedial program, the attitude of the administration, the attitude of the peer groups—all help determine whether the student will be science shy or science prone.

We have discussed briefly in Chapter 3 some of the many types of science-shy students. In this chapter we shall center our attention on the major problem which confronts the teacher: how to teach those students who are science shy because they are limited in their ability to form concepts even under the most favorable conditions. (These are the students sometimes called "slow learners", they are a large portion of the science shy.) The kind of science taught under the label "college preparatory" is not for them. Abstractions baffle them: mathematics above addition, subtraction, and division is *terra incognita;* they fail algebra; memorization of material which they do not put into almost immediate use in daily living has little

[3] Unpublished results—Paul F. Brandwein.

appeal to them; their attention span is low (ten to fifteen minutes of class time), and indeed, they are readily distracted. They are not college-destined; high school is terminal for them—if they can be graduated at all. These students are science shy because they are limited in the abilities required for learning concepts; they are limited in intelligence. They are generally students within the range of mental abilities of the class described in Table 8-1 (p. 153); their I.Q.'s span from 80 to 95,[4] their reading and mathematics scores from 4 to 7 (ninth grade). They are science shy and too many times "course shy." But they will be citizens; they will vote; they will make decisions which affect all of us, and some of these decisions will have a base in science. They will be reasonably successful in the ordinary business of living; they will be as happy, or as unhappy, as any of us.

We shall describe here the elements of a successful and practical program as conducted in one high school for those science-shy students who are slow learners. Consideration of one school's program, with which the authors are intimately familiar, should provide a better picture of the inner details of class planning and operation, of students' problems and help, than would a more general summary of many schools known only casually. This particular program includes aspects of research with slow learners which have bearing on classroom practice through the factors stated on the previous pages.

We believe that the *principles underlying this program are applicable to all schools.* We believe further that a good number of the *practices* are applicable to all schools, large or small. At the very least, this program will furnish elements from which the reader can create his own inventions to suit his own preferences and his teaching situation.

Lest there be confusion, we are *not* dealing in this chapter with the severely handicapped or with mentally retarded children; they require considerably different teaching conditions and specially trained teachers. Mentally retarded children can rarely attain the concepts reached by children with I.Q. scores above 80. There are, by definition of the I.Q. scale, a very large number of children with scores between 80 and 100; in fact, over one-third of the total population falls into this group. They have many intellectual needs, but, within school, perhaps even more intense emotional needs because they have often failed and been scorned as misfits or outcasts.

In our high-speed, easily baffling world, the slow-learning child may acquire a habit of achievement and success at his own level of ability only within an atmosphere of emotional security. Lacking this he rebels or completely withdraws from a hopelessly confusing environment. Not wishing to fail again on seemingly impossible tasks, he simply may not attempt the task, and sometimes may not admit that it even exists.

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[4] Our arbitrary limit of 80 to 95 is based on observations and general practice. Our science-shy student is above placement in the mentally retarded group. He is more educable if he is taught to read and to deal with arithmetic to his upper ability.

An approach to teaching the slow learner

The approach to successful teaching of the science shy begins not with developing a curriculum, nor even with a testing program, but with the selection of a teacher to guide these youngsters. Here, as always, the teacher is the key; moreover, here the teacher is the limiting factor. The gifted student, or rapid learner, may persevere and overcome the handicaps of unsympathetic, college-preparatory-oriented teaching. The slow learner will not persevere; he will drop out of school. Does this seem too dogmatic a statement?

Early in the history of this large school with which we are familiar, it became evident that slow learners, in the regular heterogeneously grouped classes, generally became science shy; they failed the required courses which were the established[5] ones throughout the country. This occurred mainly because:

1. The stress in the ordinary course is on memorization of materials unrelated to life.

2. Slow learners, in these established courses, generally had inadequate academic tools as shown by their low reading scores and low arithmetic scores.

3. Low reading scores and low arithmetic scores usually, though not always, went with low I.Q. scores.

4. The majority, though far from all, of the slow learners came from the lower socio-economic groups where the expectancy of entering college is rarely an effective motivating factor.

Organizing the class and program

The program reported here sheds light on the practices necessary to develop these youngsters' abilities to their fullest. It consisted of organizing a class, homogeneously grouped, to study "experimentally" certain practices and, later, to introduce the useful practices into all classes where they were relevant. The teachers involved felt that it was necessary, not merely to read about "successful" practices, but to *try them at least once* with appropriate groups of students. The practices were also tried, and confirmed useful, in other departments of the school.

One class contained 31 students who had a record of failure in science and mathematics courses and whose I.Q. scores, reading scores, and arithmetic scores were low (see Table 8-1). These ninth grade children, also described in Table 3-2, had an average age of 15.5 years and scholastic averages generally below 65. Most of the teachers involved in the formation of this class felt that such homogeneous grouping was undesirable; nevertheless,

[5] We shall define "established" as those commonly taught for the I.Q. range of 110; these "successful" courses are those generally found in textbooks

they wanted to study the possibilities attainable with such a group. As we shall see, the attempt was successful and informative.

These students were placed in a "core program" (see Chapter 18 for more on core programs). During an eight-period day they were together most of the time, but still had two subjects (health and physical education, plus music or art) outside the "core." Three periods daily formed the center of the core, whose central topic was "Understanding Ourselves and Our Community." (Note the emphasis upon themselves at the center of this study.) Through this topic they learned science, mathematics, civics, and communication skills from two teachers working together. One period was used for supervised study within the same classroom. Lunch took another period. The final period each day was reserved for special skills; this was often used for group or individual remedial assistance. In addition, all these pupils had the same homeroom teacher.

The underpinning of an approach with slow learners consisted in emphasizing four things (each discussed under a separate heading below):

1. *Guidance.* aimed with concentrated effort at reinforcing goal seeking through regular discussion of the purposes of the work planned.

2. *Planning:* aimed at improving the relationships of teacher and students through joint planning of work to be done.

3. *Special curricular design:* aimed at developing only the most significant learnings, through teaching less but teaching the important things well.

4. *Special teaching pattern:* aimed at maintaining interest through use of the most effective devices, whether auditory, visual, manual, or the like.

Guidance

The slow learner brings himself to the attention of teachers by his failure in tests, or in the daily "test": class discussion. There his failure to handle concepts is apparent. This, in addition to the pupil's record on past accomplishments, should be a sign to the teacher, and usually it is. Often, however, the teacher can or does do little about it. Often we hear that the teacher has too many students and cannot find the time to help a few slow ones. Other times we hear that "standards must be maintained in my classroom." In some schools it would seem that the student who has failed a course has failed society and disgraced himself and mankind. Yet, by definition, only a little more than half of the children in junior high school can have I.Q. scores above 100 (some of the students with the lower I.Q.'s will be in special schools or classes for the mentally deficient). Also we know that intelligence is a strongly inherited characteristic and that parents of high ability often nurture similar abilities in their children. But no child can choose his parents. Does it follow then that some children must fail so that we can demonstrate that we have "standards" in courses? Does the compulsory school attendance law foredoom many children to continuous failure until the age of 16? Surely there is a need for wisdom and humaneness expressed

through guidance which must do two things: help the student understand himself, and help the teacher aid the student.

In the program we are describing, the homeroom was a group guidance period. And once a week during the three period core there was group guidance But, in addition, since a good deal of the work was planned individually and in small groups, there was individual guidance throughout. That is, the boy or girl had opportunities to "talk himself out" to the teacher.

During the group guidance periods the students introduced and discussed such topics as:

What kinds of jobs ace there?
Dating. (How late? When? Where?)
What is the purpose of school, anyway?
How do we get along with certain teachers?
How can we memorize better?
How can we study better?
What subjects should we take?
What is college good for?

Individual discussions were around private and personal affairs. They concerned themselves with problems of getting along with individual teachers and individual boys and girls, with failure, jobs, shyness, aggressiveness, disciplinary problems, and just psychodramatic, or role playing, talk.

In any event, the boys and girls in the course were helped so sufficiently by this program, in which guidance played such a large part, that about 85% of those enrolled in these courses over several different years (following the work described in this chapter) remained in school until graduation. In the control group, only 60% remained.

Planning

To those who are convinced that this kind of teaching ignores subject matter, the idea that students, particularly these students, can take part in planning the course may be quite a shock. Yet planning, intelligently done, allows students who do not understand the function of education and who have lost faith in scholarship to begin to understand the reasons for their failure, and to gain confidence in planning their own individual work, now and in after school years.

Now planning does *not* mean abdication by the teacher. It merely means that teacher and students respond together to the question the teacher asks: "What shall we work on this term?" Answering this question implies that students will look back at the work they have done in the past, judge whether they understand it, and list topics which they would like to study. In our experience this results in listing too many topics; hence thece is a

TABLE 8-1 *A ninth-grade class of the science shy*

Entering class (entered 9/49)		*I.Q. scores*			*Reading scores*			*Arithmetic scores*		
		p.s.*	9/19	3/50	p.s.	9/19	4/50	p.s.	9/49	4/50
BOYS	1	84	95	110	7.7	8.6	12.0	4.8	5.8	7.6
	2	92	abs.	97	6.5	abs	6.9	5.8	abs.	6.6
	3	85	98	—	6.9	8.1	12.4	6.1	5.2	8.7
	4	72	77	76	6.3	6.6	5.0	—	4.4	5.0
	5	83	101	99	6.8	8.3	8.9	7.7	8.6	9.0
	6	87	84	101	7.2	9.0	9.2	4.3	7.9	8.6
	7	88	95	105	6.7	7.4	9.5	9.1	9.3	12.0
	8	83	83	78	5.8	8.1	6.0	6.6	6.5	7.2
	9	83	96	98	7.0	7.3	8.7	9.1	11.0	12.0
	10	80	92	96	5.6	6.2	9.2	7.7	8.8	12.0
	11	82	88	100	6.4	8.3	9.6	7.7	7.2	9.0
	12	89	94	96	6.5	7.8	8.0	6.7	8.8	7.5
	13	85	89	94	7.2	7.3	8.1	6.0	7.2	11.0
	14	89	abs.	89	5.9	abs.	drop	5.8	abs.	drop
GIRLS	1	85	abs.	101	7.3	abs.	8.3	7.7	abs.	12.0
	2	83	90	97	7.5	7.6	8.0	9.4	12.0	12.0
	3	85	abs	92	7.0	abs	7.9	9.4	abs.	10.9
	4	91	102	101	7.4	6.9	7.8	7.7	7.9	9.0
	5	79	93	91	4.6	5.6	8.6	6.4	12.0	12.0
	6	87	99	110	8.7	8.3	9.0	6.4	9.3	12.0
	7	81	99	92	6.9	6.7	7.6	5.2	6.2	10.0
	8	74	73	82	7.0	6.4	7.9	5.0	5.8	6.2
	9	66	88	98	7.1	5.5	6.9	6.6	9.3	11.2
	10	87	81	86	7.5	7.3	drop	7.9	7.7	drop
	11	82	88	88	6.1	5.4	6.6	8.3	7.9	11.3
	12	75	87	81	6.1	7.4	6.2	6.4	6.9	9.3
	13	89	89	90	7.4	6.4	8.0	7.4	7.9	8.0
	14	94	101	106	9.4	9.6	9.8	5.6	6.5	6.7
	15	87	92	101	6.4	7.8	8.6	7.2	7.2	11.6
	16	85	88	88	6.8	5.1	7.0	9.1	9.3	10.0
	17	75	81	82	5.2	5.9	6.2	5.8	5.7	6.0
CLASS AVERAGE		82.7	90.3	91.5	6.8	7.2	8.3	6.9	8.0	9.6

* Previous school.

necessary choice of the most important for study in class. Usually the students will agree to undertake reading on the other topics out of class and report to the others in class.

In short, with slow learners, especially, we have found the democratic-planning approach of Mr. P. (Chapter 4) exceedingly useful. And we repeat, because there is considerable misunderstanding of the results of planning, that *more* subject matter is learned when students help in planning the course than when students submit to complete authority or when they dominate through a laissez-faire approach. It is well, however, to remember that slow learners are not college-destined; one need not assume that established courses and the memorization of the standard material will serve them best.

In any event, slow learners greatly need to develop confidence in the

school, in the teacher, and especially in themselves. Planning the course with them helps to do this.

Special curricular design

Slow learners do not seem to succeed in the kind of mathematics (particularly the abstract symbols of algebra) which is required of most college-destined students. Neither do they succeed in courses requiring a great deal of memorization, for example, classical or foreign languages.

There are those who have said that, this being so, these students should not be in high school. Possibly so; but their parents, fellow citizens and taxpayers, wish it otherwise. They want their children educated to the best of their ability, and the state legislatures have passed compulsory school attendance laws. Slow learners *are* interested in science and can succeed in it, if the course is divested of detail meaningless to them (memorizing insect mouth parts, classification, chemical formulas, and the like; in short, information they can look up if they ever want it).

For the students listed in Table 8-1, the practical curriculum offered consisted of general science, biological science, and physical science (a one year course, see Chapter 16), nonalgebraic in nature but including the necessary arithmetic and dealing with relevant materials, for example: [*]

Not the chemistry of preparation of bromine and of electronic balancing, but the chemistry of materials found in the home (sodium bicarbonate, soap, etc.).

Not the anatomy of the perch, but the anatomy of man.

Not the physics of the Wheatstone bridge, but the physics met day in and day out by the students.

Special teaching pattern [†]

This pattern, we believe, is the key to teaching the science shy student. We believe it was responsible for the success reported in Table 8-1: general raising of reading, arithmetic, and I.Q. scores. Furthermore, about 85% of the youngsters enrolled in the general science classes in two successive years stayed the four years of high school. (These youngsters, it will be remembered, also had instruction in English and social studies adapted to their abilities and needs.)

In the two control classes (two also in three years), I.Q., reading, and

[*] See Chapters 12 through 16 dealing with the structure of these particular courses

[†] Although this is a description of an actual case of dealing with the science shy, it is a distillation of the best practices resulting from many observations of teachers specially experienced in teaching slow learners. Also different approaches described in the literature cited at the end of the chapter were adapted to our use.

arithmetic scores changed little; and, as was indicated, only 60 per cent remained until graduation.

The pattern used, recounted below, is a reasonable one. This teaching method is useful within a core, or in special classes, and we believe that it is generally effective.

Note we say "teaching pattern." Often the expectation is, especially by inexperienced teachers, that there is one teaching *method* which is best for this group or that. The search for the equivalence of the philosopher's stone in teaching is futile.

When one has a teaching problem, one asks "why," then "how." The "why" we have discussed in the previous sections of this chapter: we have expected of the sparrow the flying speed of the swallow. Worse than that, we have tried to force the sparrow to fly at the speed of the swallow, the sparrow has failed; the sparrow, furthermore, has shown resentment, has rebelled, and has finally been defeated. If we were only dealing with sparrows! *We are not.* We are dealing with human beings, and each human being has dignity and moral worth of his own. Is this to remain merely a slogan, or can it actually be expressed in our behavior?

In the method practiced our major purpose was to have these boys and girls regain faith in themselves; but we were not content with that. Once faith was regained, it was to be followed by good work. Good work was defined as work to one's capacity More than that, the student was expected to work affably in response to what must have been for him a very difficult school situation.

Let us assume that the first weeks of the term are over. During this time we have discovered what interests these students. We have determined what they would like to learn, discussed their suggested topics in class, and finally decided upon a "first" topic. We have established rapport. At least the students recognize that we are not interested in finding out what they don't know, but rather what they do know and, furthermore, that we are interested in helping them.

The pattern of the lesson. One of the first things a teacher learns about slow learners is their relative inability to give attention over the full span of the "normal" period. Forty to sixty minutes in a given activity, particularly if it is listening, or even discussing, seems too much for these students. We therefore divided our period of 40 minutes into three subperiods of roughly 10, 15, and 15 minutes. Toward the end of the term we were able to have only two subperiods of activity, of 10 and 30 minutes. After seven months (we had these youngsters for a year), the full 40 minutes could be spent profitably on almost any simple activity, and with "good discipline."

To the reader: In the control group where the "normal" pattern of a 40-minute period was maintained, there were often interruptions in the work

due to "poor discipline," i.e., excessive talking, inattention, even a scuffle here and there. Perhaps you have heard of similar "difficult" classes.

THE FIRST SUBPERIOD (10 MINUTES). The lesson generally began with an interest-begetting activity. But in this case the beginning activity (the pre-Eureka, see Chapter 6) was usually "visualized"; it was *an activity in which all participated*. For instance, in general science—

A lesson on respiration. "Take a deep breath. Hold it as long as you can. Then explain what happened in your lungs."

A lesson in wiring a circuit: Screw drivers had been brought from home. All had the problem of wiring a lamp so that it would light. They worked in groups of four.

A lesson on the action of leavening agents: All prepared dough, some with yeast and others with baking powder. They worked in pairs.

In each one of these examples either the text or mimeographed material was available for reference. To our minds, this is one of the most important procedures to be followed with slow learners. wherever possible the activity should include *reading* for a clear purpose, because, generally, these students have low reading scores. Also, wherever possible their activity should include *working with others,* because they often display poor discipline, which may be defined as an inability to work with others. Within an interesting context we can encourage both reading and working with others.

After the students finished the initial motivating activity (and different students did so at different times), they were asked to *write down* a summary of what they had done or observed. This writing activity followed every activity period. During this very brief writing period, consulting with neighbors was discouraged. The students could consult their texts, the dictionary which had been given to each of them in addition to their texts, and a small reference library in the classroom.

Also, while the students were writing down the summary of their "motivating" activity, the teacher was often visiting with them; he would sit down beside a student and talk briefly with him as he examined what was written. At first the students were very self-conscious and ill at ease, but soon they learned that he was there to help. In this way, the teacher was able to have six to ten individual chats a day. Every lesson portion culminated in a writing activity: during each writing activity the teacher visited several students. We consider this procedure of the *individual visit* exceedingly important with all students, but especially with slow learners.

THE SECOND SUBPERIOD (15 MINUTES). The next portion of the lesson was given over to discussion of the topic of the lesson proper; the motivating period was to be milked dry. The boys and girls had written down their impressions, and had referred to a text; they had a good idea of what was to go on. In many cases, considerable interest was generated.

For the discussion period a single rule was instituted by the teacher;

he said, "Only one person talks at a time; when I talk you should not talk, and when you talk I shall not interrupt." After a number of reminders, students could carry on a discussion. Another help was offered them: When they wanted to speak, they raised their hands to the student speaking (he faced the class); he called on the volunteers. Soon the youngsters got into the habit of calling on each other; the "recitation" became socialized; that is, it became a *discussion*. We consider this procedure important; the lesson is not to be a recitation to the teacher, but a discussion by the class in which everyone participates.

What was the teacher's function? He raised his hand to the speaker on the floor when he had a question. Most of his questions were designed to move the discussion along the road toward a solution of the "problem," or to question an incorrect statement. For example:

1. Who will find out what an x-ray is? Will you report to us? When will you be ready? How long will you need for your report? (These individual reports were limited to three to four minutes per person. A single oral report by a committee was normally not allowed more than 10 minutes; a longer time was allowed only if visualization such as a film, filmstrip, or demonstration was used.)

2. How does steam make the wheels of an engine go? (After a youngster had remarked that steam "gave the push" that made an engine go.) Would you like to see this at work? (A field trip to the boiler room was planned as a result.)

During the discussion the youngsters were expected to write down a *summary*. When the discussion ended, they were expected to volunteer to read this summary of it to the class. We consider this procedure important; slow learners generally seem not to be able to write down summaries of what they hear. Hence the need to give them an opportunity for the activity of preparing written and oral summaries.

The net result, then, of the first 25 minutes was what might be considered the ordinary lesson of 40 minutes. The time has been saved mainly in the extent of the topic covered and the detail with which it has been analyzed. For instance, the topic "What is an electromagnet?": for motivating activity, groups of four students made an electromagnet (spike, coiled wire, dry cell, brads); the discussion period was spent in comparing an ordinary magnet, and how it worked, with the electromagnet. The youngsters took quite a bit of time to demonstrate that it must be the electric current which made the metal magnetic. Simple? Yes! But for whom?

THE THIRD SUBPERIOD (15 MINUTES). This consisted of an extension of the lesson and preparation for the next day's work. To continue the example: The students read about electromagnets in their texts and other reading materials. They read this material in class, and took notes on it.

We consider this procedure important with slow learners especially; youngsters who have not had experience in study should have that experience

immediately after the activity for which study is desired. This seems to help these youngsters milk their experiences dry; in addition, it helps set a pattern for home study.

In any event, we find that youngsters who *do* an activity, *discuss* it, then *read* about it, in a continuous time sequence, reinforce their understanding of what has been going on. And each time they culminate their experience by *writing* down a summary of their understanding.

We have said that the lesson was really three lessons: 10 minutes of motivating activity, 15 minutes of discussion, and 15 minutes of study through reading and writing. We might have said four lessons: at the end of the class the youngsters noted the lesson planned for the next day; this was the "assignment" placed on the board by a committee which had helped the teacher organize the work related to the topic (Chap. 7). The last three to five minutes, therefore, were usually given over to examining the next day's work in the text, or on the bulletin board, or through the showing of a few frames of a filmstrip dealing with the coming lesson.

This was to help students in their home study of the next day's work. We found it rewarding to take the time to help students direct their home study.

Now one might think the lesson was highly structured. Structured is hardly the word; it was *planned meticulously* in order to assure the complete involvement in learning of students who had "failed" in their work, to recognize their low attention span, to overcome their difficulties in communication skills (reading, writing, and discussion), and to help establish the healthiest kind of rapport.

Slowly, but with a commendable, recognizable shift, these students gained *confidence* and began to assume a degree of *competence*. They began to engage in intellectual activity, in begetting Eurekas. We have reason to believe that slow learners must develop confidence in the school, the teacher, and themselves, before they can gain competence in the kind of things the school finds important.

As students obtain confidence in themselves it is a glorious—yes, glorious—surprise to the teacher to find that they know a great number of very useful things, and are willing to work. For instance, in a group of youngsters who had "failed science," two of them knew more than we did about the practical working of the gasoline engine; one collected insects; another was an expert with pigeons; another with tropical fish; others knew a great deal about boats, horses, cooking, jazz, painting, carpentry; and half the class could speak another language, among many other things. One boy who translated Redi from the original Italian (with help on the technical vocabulary) learned to his joy that his other language, of which he had been ashamed, was an asset.

In short, these youngsters began to attain status. *To stay in school, to continue learning, it seems fairly clear, one must have self-esteem and status.*

The pattern of the day. For our slow learners, we had determined on a core program. In the ninth grade, this meant a program as follows:

Period 0 Homeroom (10 minutes: one 30-minute guidance period once a week)

Period 1, 2, 3 Core

4 Study—lunch (conference)

5 Study—lunch (conference)

6 Health—physical education

7 Music—art

8 Special skills—remedial work in math, science, or English, or study, or special projects, or time for special problems, even personal ones

Because several classes were involved, periods 4 and 5 were given over to a combination study, lunch, and conference. The eighth period was given over to remedial work in subjects or topics with which the student had difficulty. A student who had been absent could catch up; a student who had personal problems could talk them out.

The pattern of the week. Generally speaking, each lesson and each day had somewhat the same pattern.

EVERY WEEK. One of the five weekly "periods" in science was spent in supervised study of written instructional material. The aim was to help students gain skill in using books, in understanding what they read. The technique used during these periods was as follows:

The students were introduced to the technique, when first they asked for textbooks, of "looking up" certain materials. (We prefer to give students their texts when they ask for them; too often the distribution of textbooks is made routine and matter-of-course, when it could pack "motivating" power.) In a joking way, the teacher remarked, "I suppose you have used textbooks before." When students nodded, he said, "Open your text to page 127." The teacher then asked the students to read silently a paragraph on the page selected.

To the reader: Won't you do this now? Read paragraph 1 on page 37. When you finish reading the paragraph turn back immediately to this page, then follow the instructions given in footnote 8 on p. 160.

Of course, you didn't have any difficulty. But in our experience most, if not all, students at the junior and senior high school level, slow or rapid learners, are unable to do this. They have not gotten into the habit of reading for meaning. But the procedure and the request are repeated: "State the major thought of the paragraph as briefly as you can, in one sentence if possible." A few students now are able to do it; but what is more important, the students now know what to look for.

notebooks; for the next two tests, only their notebooks. Thereafter they were to rely on their increasing ability to sustain themselves.

EVERY MONTH. Each month the youngsters had a full-period test for which preparation was made in class. Two days were spent in review of materials learned. One period was spent on a test involving short-answer "situations" (Chapters 19 and 20) and essay items. The next period was spent in discussing the test. A good deal of time was spent in discussing how to "take" tests.

The first month's test was given as a sample; the youngsters did not turn it in unless they wished. The second month's test and those thereafter were turned in.

This procedure in testing seems to be comparatively unique and we earnestly recommend its trial. The test developed was liked by the youngsters, or at least it was faced without the usual distress; parents liked it as well; it had the interesting characteristic of stimulating youngsters to study and to read beyond the requirements of the day. It has always worked for us. The test is fully described in Chapter 20.

Why spend so much time on this procedure? Because these students, these slow learners, had a mortal (is the word too strong?) fear of tests, which they had so often "failed." Their confidence had to be built almost afresh. They needed to discover that tests could be used to determine what one understood, what one had failed to understand, and how one could continue to grow, to advance.

Special techniques. Whenever one attends meetings dealing with effective methods of teaching slow learners, one finds stress placed on the use of visual aids (see Section V, Tools for the Science Teacher: The Film, The Chalkboard, The Filmstrip, The Field Trip, etc.). Yet it is not through the extensive use of visual aids that special help is given slow learners, but through *the way they are used.* In our experience, the best way of using visual aids consists in our central aim in developing teaching technique to be interesting, not boring; and in so doing, to make students do their "damnedest with their minds, no holds barred." This applies to all learners, whether they are slow, moderate, or rapid.

What then are the differences in dealing with "slow learners," the science shy, as compared with the "rapid learners" or "moderate learners"?

1. In the *supportive* technique used by the teacher. Slow, moderate, and rapid learners need support, but slow learners need the most support. Slow learners have failed previously and need successful practice in the things demanded of them in school. (Rapid learners have succeeded in the things demanded of them in school, but need support in inventing, in imagining, in breaking away from conformity to the things which denote school success.) Slow learners need, in short, to attain status. Such remediation as is practiced should be done in full realization that its intention is to be supportive.

2. In the expectation of *the kind and amounts of success* to be attained by slow learners.

In addition, the students are asked when they read anything to write down their brief summaries of major thought, paragraph by paragraph. They then have a summary for ready reference of what they have been reading.

This simple technique was the central one in helping students to improve their reading and study habits. Once a week a lesson was selected for study in this way. The motivating activity was still a demonstration, a class activity, a film, or a filmstrip, but the next two subperiods (15 minutes each) were devoted to solving by *reading* the "problem" raised in the motivating activity. After the first 15 minute period, several minutes were taken to permit the reading aloud of some of the summaries.

Naturally, the students were taught also how to use the table of contents, index, glossary of the text, and the dictionary (abridged and unabridged), as well as the library. Once a month a lesson which demanded going to the library was planned.

We believe this is another important procedure with slow learners: they need the opportunity to *learn to read for meaning*. By the way, students regularly reported that they had reduced the time needed to do their homework after they learned this technique. And generally speaking their reading scores went up. (The reading scores of the control group went up also, but, with the exception of two students, the rise was not as remarkable as in this "experimental" group.)

At the end of two months students generally were using their notebooks well, they were reporting in them summaries of major ideas gleaned from class discussion, from observing films, filmstrips, and demonstrations, from participating in laboratory work, and from reading.

Soon we found that some youngsters learned to read very well; their test scores showed that, in one sense at least, they could go into the "normal" stream. These were permitted to replace the supervised reading period with a project period. They worked on such projects as are listed in Section V, Tools for the Science Teacher: The Project.

At the end of the term each youngster had developed at least one project of his own. We gave over a week at that time for youngsters to present their individual projects to their classmates. We also had a small "Science Fair" with three prizes for the best exhibits.

The core idea lent itself exceedingly well to the project idea, because on one day or another two, or even three, periods could be given over to the project, or to any individual or group activity, such as a play or a field trip.

EVERY TWO WEEKS. Every two weeks the youngsters had a short test which they themselves corrected and, for the first two months, did not turn in unless they were satisfied with their grades. The test was usually a short-answer form (see Chapters 19 and 20): multiple choice items testing simple recall, some experience recall, and a "thought question" or two.

For the first two tests youngsters were permitted to use their texts and

* In a single sentence, in your own words, state the main thought of the paragraph.

difficult detail, or quantification) were directed at them. Examinations were designed in which their scores were adjusted so that if they worked to their fullest, they "passed."

In our general science courses we finally found it convenient to practice heterogeneous grouping. With all young people in their junior high school years (seventh, eighth, ninth grades; slow, moderate, rapid learners), it is a good practice to break up the period just as we did for slow learners. This helped all the youngsters, particularly those who had just come from an elementary school, to develop greater personal control. We found, too, that even the best students benefited from help in learning how to read. Since one and even two periods a week could be given over to individual work, both project and group work, ample consideration was given to individual difference. In addition, different texts were used, as well as the individualization of instruction described in Chapter 3.

After general science, there were available courses in biology and physical science which were characterized by the absence of quantification and excessive detail (see Chapters 12 and 14 on the courses in biology and physics). The justification for these courses, in a large school, resides in the fact that if students are permitted choices with intelligent guidance, they generally make sensible choices. The important thing is that no stigma be attached to the choices made. While this is difficult to attain, it is worth while to seek. And while perfection cannot be reached, a reasonably efficient operation may be established.

Grades

Inevitably, from the ways in which schools operate, grades for this group of the science shy were required. On what basis could they be given? According to the "normal standards" these students were probably doomed to failure, which is why they were in this special group. But once this was known, they could be graded on the basis of their effort, which was quite apparent, and their achievement on projects and tests. Certainly these grades could not be used for "college admission"; but no one was worried, for this was an unrealistic criterion from the start. Therefore the grades generally ranged from 65G to 90G; the G implied that this was a "noncollege" course. On the scale used, 60 was considered the borderline between failure and passing. Similar "noncollege" grades were given for the special sections in biology and physical science chosen, with advice, by these boys and girls.

Why did we develop, beyond the general science level, courses which permitted what might be called homogeneous self-grouping? A large school includes such a variety of abilities that special groups would permit children to compete with their near equals. Also the numbers involved permitted this arrangement to be economically practical. It is in practice one form of what is often termed "individualization of instruction."

3. In the *scheduling of the rate* of attainment of whatever success they achieve.

4. In the expectation of success in *quantifying* phenomena (abstract mathematics is generally not for slow learners).

5. In the expectation of success in *memorizing*.

6. In the realization of their *destination* (they are not college-destined).

Progress report

After ten months of work together in the general pattern delineated in the preceding section, the youngsters gained confidence and as much competence as the limitations of the school situation and the teacher, and their own inventiveness could muster.

The young people showed the general improvement in test scores reported in Table 8-1. Although the group was very small, and we cannot base a statistical analysis on it, one may still indicate the nature of their improvement. Furthermore, of the 31 students in this class, 27 stayed on for graduation (as compared with 17 out of 31 in the control group). Possibly these "data" may stimulate a full investigation.

The science shy in heterogeneous groups

It might be assumed that it was the core program which was the key to what the teachers participating in this "experimental work" would consider their success. On the contrary, the core idea was abandoned after two years because the teachers agreed that the significant element in the readaptation of the youngsters, their regaining of faith in themselves, was not the core approach but rather the supportive technique used. In the next three years, youngsters of the type described in Table 8-1 were placed in regular classes with science teachers who were skilled in these supportive techniques and in the teaching techniques we have recounted for the slow learners. In short, these teachers used these techniques with *all* their students—slow, moderate, or rapid. But, in addition, their instruction accounted for individual differences; that is, their expectation of success in learning was related to the realities of the learning situation and the learner. Slow learners were respected for their special abilities and limitations; and all were expected to do their best.

Thus in a heterogeneously grouped class in general science, the pattern for the first two months developed similarly to the one we have recounted for our science shy. Even the most rapid learners need to improve their skill in reading, in summarizing, in planning their work, in taking tests. Even the most rapid learners can stand supportive techniques, and do need them; expectations for their continued success are high, and these also breed tensions and misgivings.

After the first two months, special attention for the science shy was continued in several ways. In class, specially designed questions (not requiring

*TABLE 8-2 Techniques used in discovering rapid- and slow-learning pupils **

1. Teacher marks
2. Group intelligence tests
3. Teachers' estimates of school achievement
4. Information on physical health
5. Standardized achievement tests
6. Guidance counselor's appraisal of pupils' interests, aptitudes, and abilities
7. Information on vocational plans
8. Information on reading interests and habits
9. Information on home environment
10. Anecdotal reports and records
11. Information on personality adjustment
12. Teachers' estimates of aptitudes
13. Information on social maturity
14. Homeroom adviser's appraisal of pupils' interests, aptitudes, and abilities
15. Information on hobbies
16. Individual intelligence tests
17. Teachers' estimates of intelligence
18. Standardized aptitude tests in specific fields
19. Parental appraisal of pupils' interests, aptitudes, and abilities

*TABLE 8-3 Instructional provisions and procedures in science **

1. Insist that students report science experiments honestly and accurately.
2. Encourage students to use scientific encyclopedias and references in preparing science reports.
3. Include student activities to stress basic skills, such as reading tables, observing experiments, and spelling common science words.
4. Guide students' experiences in helping with science demonstrations.
5. Give students experience in helping with science demonstrations.
6. Help students understand scientific reasons for fire and safety rules, sanitary standards, and/or first-aid practices.
7. Discuss with students the qualities that help a person hold a job in industry.
8. Encourage students to read stories about famous scientists.
9. Teach students to read and evaluate science materials from newspapers.
10. Guide students to evaluate science notebook work against appropriate standards.
11. Stimulate students to plan and carry on projects of the experimental research type.
12. Encourage students to collect clippings on the uses made of science in everyday life.
13. Arrange for students to become assistants for class, laboratory, and/or science club work.
14. Encourage students to engage in recreational reading of science fiction.
15. Help students to understand how tools, such as the hammer, plane, drill, and screw driver, operate.
16. Announce and conduct discussion of radio, television, and movie presentations of scientific events.
17. Help students to analyze science information in statistical form.
18. Help pupils participate in pupil-teacher planning to discover real problems for study in science.

* From *Teaching Rapid and Slow Learners in High School,* p. 116.

Our special invention may not ultimately be satisfying to everyone, but it fitted our needs As the result of an invention which attempts to deal with all students, the school becomes a place where individuals exercise their individual differences in as individual a setting as the school can reasonably provide.

A short excursion into developing one's own approach with the science shy

8-1. On heterogeneous and homogeneous grouping, the U. S. Office of Education Bulletin No. 5, *Teaching Rapid and Slow Learners in High School*,[a] reports:

> Almost half the schools reported attempts to place pupils in ability groups of some kind Schools were asked to name the subjects for which attempts had been made to provide homogeneous groups for both rapid and slow learners, and for slow learners alone. In both instances the subjects mentioned most frequently were English, mathematics, social studies, and science
>
> Schools were invited to indicate which of the 25 administrative provisions they had tried and abandoned, and the reason for giving up any procedure. Responses to this query were meager and hardly worth reporting except, possibly, *for the attempt to group pupils homogeneously* [italics ours]. This administrative provision had been tried and abandoned by three principals of senior high schools, four principals of regular high schools, and sixteen principals of junior high schools The reasons given most frequently were· "parents raised objections," "social stigma was created," "results were not apparent," "provisions were inconsistent with the philosophy of the school," and "the staff preferred to adapt instruction to the individual pupil."

(a) What is your stand? Which is best? Is there any base in evidence that one is sounder than another?

(b) Normally is there homogeneous grouping in physical education? In art? In music? In trigonometry? In calculus?

8-2. What devices illustrated in this chapter might be useful in a small school? In a large school?

8-3. You may find it useful to compare the devices used for the science shy with those used for the science prone (Chapter 9).

8-4. Table 8-2 is a list of techniques used in discovering rapid and slow learning pupils, Table 8-3 is a list of instructional provisions and procedures in science.

(a) If you are now teaching, which are used in your school?

(b) Which would you try if you were the administrator in charge of a school?

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[a] *Op. cit.*, p 146

CHAPTER 9

Patterns in teaching science:

The science prone

A note at the beginning: In essence, one becomes a writer by writing, a painter by painting, a scientist by "sciencing," a mathematician by "mathematizing." And the sooner he writes, or paints, or does science or mathematics, the sooner he creates, the sooner he actually becomes a writer or painter or scientist or mathematician. A course in which the youngster has an opportunity to create fits our gifted, or science-prone, students who are expected to become, among other things, our "doers," our "creative minds," our innovators and inventors, our originators in all areas. Certainly it is essential for young people to study textbooks and to repeat experiments via the workbook and manual, for the knowledge gained is essential to the preparation of all cultured men—scientists and mathematicians among them. A course in "Great Experiments" or "Great Laws" or "Great Principles" (our present courses in science and mathematics) is just as valuable as a course in "Great Books." But it is hardly sufficient. To originate, boys and girls must have opportunity to "create" on their level. This implies both time and motivation, within an encouraging school atmosphere. These in turn imply a teaching method which recognizes pupils' strengths and abilities, as well as their weaknesses and lack of experience. It means constant labor, a scholar's attitude, and work.

We should like to discuss the methods of dealing with creative minds under the rubric of "science proneness." The term does not seem especially appropriate, but "gifted," "rapid learner," "science talented," and the like, seem even less appropriate because they assume a difference both qualitatively and quantitatively in the students we are trying to assess. Again we follow our own general policy; the chapter is intended to help the reader develop his own personal invention in method of dealing with the "science prone."

8-5. Which provisions in Tables 8 2 and 8 3 would you use for the "rapid learner"? The "slow learner"? The "moderate learner"? Which provisions in this chapter would you try for the "slow learner"? The "moderate learner"? The "rapid learner"?

8-6. There is a wealth of published material on the science shy. Perhaps some of the references below will be useful to you in developing your own inventions

Allen, A. A, *Let Us Teach Slow Learning Children*, rev. ed, Columbus, Ohio State Department of Education, 1955.

Cappa, C., and M Pines, *Retarded Children Can Be Helped*, Great Neck, N. Y.: Channel Press, 1957

Cleugh, M F, *The Slow Learner Some Educational Principles and Policies*, N. Y.: Philosophical Library, 1953

DeHaan, R F., and J Kough, *Identifying Students with Special Needs*, 2nd ed, Vol 1, Chicago: Science Research Associates, 1956

"The Education of Handicapped and Gifted Pupils in the Secondary School," *National Association of Secondary School Principals Bulletin*, Vol 39, No. 207, Washington, D C, Jan 1955.

Featherstone, William, *Teaching the Slow Learner*, rev. ed, N. Y.: Bureau of Publications, Teachers College, Columbia University, 1951.

Heck, Arch O, *The Education of Exceptional Children*, 2nd ed., N. Y.: McGraw-Hill, 1953.

* Heiser, Karl, *Our Backward Children*, N. Y.: W. W. Norton, 1955.

"High School Methods With Slow Learners," *National Education Association Research Bulletin*, Vol 21, No 3, Washington, D. C, Oct. 1943.

Kirk, S A, and G. O. Johnson, *Educating the Retarded Child*, Boston: Houghton Mifflin, 1951

* Kirk, S. A, M. B. Karnes, and W. D Kirk, *You and Your Retarded Child*, N Y: Macmillan, 1955.

Lightfoot, G., *Personality Characteristics of Bright and Dull Children*, N. Y.: Bureau of Publications, Teachers College, Columbia University, 1951.

* Loewy, Herta, *Training the Backward Child*, N. Y: Philosophical Library, 1956.

Martens, E H, *Curriculum Adjustments for the Mentally Retarded*, U. S Office of Education Bulletin No 2, Washington, D. C, 1950

National Society for the Study of Education, *Forty Ninth Yearbook*, Part 2, *The Education of Exceptional Children*, Chicago U. of Chicago Press, 1950.

The Slow Learner in the Average Classroom, N. Y.: Metropolitan School Study Council, 1954

Teaching Rapid and Slow Learners in High School, U. S. Office of Education Bulletin No. 5, Washington, D C: U. S Government Printing Office, 1954.

Wallin, J. E. W., *Education of Mentally Handicapped Children*, N. Y.: Harper, 1955.

* These books are mainly for parents

sider one of their conclusions particularly useful in developing a teaching invention:

> These findings suggest that an acceptable criterion for exceptional performance in science and other academic areas must be sought outside the province of intelligence. Apparently there are forces other than intelligence at work leading to exceptional achievement in science and other areas, such as motivation, originality, and creativity.

The predisposing factors

The characteristics grouped under the predisposing factors consist of two major ones. The first includes a group of traits which we call *persistence.* This consists of at least three attitudes:

1. A marked willingness to spend time, beyond the ordinary schedule, on a given task; this includes the willingness to schedule one's own time, and to labor beyond, say, a "9-to-5" day.
2. A willingness to withstand discomfort; this includes adjusting to shortened lunch hours, or no lunch hours, working without holidays, withstanding fatigue and strain, and working even through minor illness, such as colds or headaches.
3. A willingness to face failure, with this comes a realization that patient work may lead to successful termination of the task at hand.

The second characteristic within the predisposing factors we call *questing.* This attribute is shown by a continuous discontent with present explanations of the way the world works—that is, a discontent with present explanations of various aspects of reality.

Roe, Kubie,[2] and other qualified workers are entering upon a study of this most important phase. Although we are not psychologists or psychiatrists, we doubt that questing necessarily originates in neuroses or traumata in childhood. Possibly it has its origin in the mechanisms of sublimation. But further comment on the origin of this behavior is best left to others more qualified to study and speculate upon the scientist's inner life.

However, it may be useful to describe what questing is *not.* The superficial "so what?" attitude is *not* characteristic of questing. The general acceptance of authority in a given field of scholarship without question and without ascertaining the reliability and validity of that authority is *not* characteristic of questing.

It seems clear that genetic and predisposing factors are not the only ones operating in the making of a scientist. Opportunities to get further training and also the inspiration of individual teachers are additional

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[2] A. Roe, *The Making of a Scientist,* Dodd, Mead, N. Y., 1953.
L. Kubie, "Some Unsolved Problems of the Scientific Career," *American Scientist,* Oct. 1953, pp. 596-613, and "Socio-Economic Problems of the Young Scientist," *American Scientist,* Jan. 1954, pp. 104-12.

The nature of science proneness—a working hypothesis

If there is any lesson to be gleaned from a study of modern genetics, sociology, and anthropology, it is that the organism is a product of its heredity and its environment. Indeed one of the major conceptual schemes of our century is that the individual and his environment react upon each other. Even if we were to assume that high ability in science (science proneness) was primarily an inherited factor and was identifiable as such, we could not assume that it would automatically mature. We should need to assume that high ability will be *expressed most favorably in the most favorable environment.*

As a working hypothesis we assume that, whether or not high ability in science can be identified as a hereditary factor, whether or not it can be identified by testing devices, it will still be exhibited at its highest level in the most favorable environment.

Genetic factors [1]

Observation of research scientists at work shows that high verbal ability (oral or written) and high mathematical ability generally characterize those who remain in scientific research. The operations of the modern scientist indeed require that he report his findings to his colleagues orally and in writing in acceptable English and often in acceptable mathematics. High verbal and mathematical abilities we have called genetic factors. They appear to have a relationship to high intelligence and *may* have a primary base in heredity.

There are, of course, other genetic factors. Among these are adequate neuromuscular control, especially of the hands, and at least adequate vision

All these factors are usually necessary but not sufficient for success in science, for any individual is the product of both his heredity and his environment. We can recognize the hereditary components and modify the environmental ones.

Do these characteristics we call genetic factors assure success in scientific study and research? Here, observation of graduate students is useful. We can use acquisition of a Ph.D. in science as an acceptable index of commitment to scientific research, though not necessarily of high success in such research. Why do certain graduate students of high ability fail in their work? This leads us to the isolation of a second heading which we call the *predisposing factors*—factors "outside" the general sphere of intelligence.

In a significant paper [2] Anderson, Page, and Smith analyze, among other things, the degree of relationship existing between science achievement and ability in other areas; they also analyze variability in achievement. We con-

[1] The term "genetic factors" is used to describe characteristics with a base in intelligence and general muscular control, which are now accepted as hereditary characteristics See L. M. Terman *et al*, *Genetic Studies of Genius*, Stanford University Press, Stanford, Cal., 1925 47, 4 vols. The term "genetic" is used here in the same way as it was used by Terman.

[2] K. E. Anderson, T. C Page, and H A. Smith, "A Study of the Variability of Exceptional High School Seniors in Science and other Academic Areas," *Science Education*, Feb. 1958, pp. 42 59.

sider one of their conclusions particularly useful in developing a teaching invention:

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Roe, Kubie,[3] and other qualified workers are entering upon a study of this most important phase. Although we are not psychologists or psychiatrists, we doubt that questing necessarily originates in neuroses or traumata in childhood. Possibly it has its origin in the mechanisms of sublimation. But further comment on the origin of this behavior is best left to others more qualified to study and speculate upon the scientist's inner life.

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[3] A. Roe, *The Making of a Scientist,* Dodd, Mead, N. Y., 1953.
L. Kubie, "Some Unsolved Problems of the Scientific Career," *American Scientist,* Oct. 1953, pp. 596-613, and "Socio-Economic Problems of the Young Scientist," *American Scientist,* Jan. 1954, pp. 104-12.

factors to be considered in reaching a working hypothesis on the nature of high-level ability in science.

Activating factors

Knapp and Goodrich[4] have studied the place the college teacher has in stimulating individuals with high-level ability in science. Time and time again, without exception, the working scientists with whom we have talked have stated their indebtedness to one or more teachers and cited the opportunities these teachers made available to them. On this basis, it seems reasonable to assume that another major factor needs to be added to the two already stated. This we call the *activating factor*. This factor is concerned with opportunities for advanced training and contact with an inspirational teacher. Without activation, potentialities may be lost or turned to other areas.

As a result of these preliminary excursions into the problem of what makes a scientist, this working hypothesis on high ability in science is put forth tentatively:

High ability in science is based on the interaction of several factors—genetic, predisposing, and activating. All three factors are generally necessary to the development of high ability in science; no one factor is sufficient in itself.

The ambiguity and tentativeness of the hypothesis are deliberate: we are trying to investigate an element in social behavior (high ability in science, science proneness, giftedness) which has not been clearly defined in operational terms. Here we are caught on the horns of the usual dilemma of the investigator of social events. We need to define the trait so that we may observe it But when we arbitrarily define it, we run the risk of not knowing what attributes and behaviors to observe.

Cureton[5] has made the point that we are on relatively safe ground at the start, if we admit that we are operating in an ambiguous area. Then an investigator may at least state his hypotheses to his own satisfaction, provided they are not ambiguous to him, and proceed to test them in the light of clearly understood operations. As he learns more and more, his hypotheses and observations clarify themselves, one in counterpoint to the other.

Now what detailed information do we have about the occurrence and relative importance of the various factors we have postulated? The literature cited, and additional references at the end of this chapter indicate that these factors and perhaps others are important, but in what combinations and to what extent? Once again, as in the previous chapter, we turn to a long-term investigation with which we are intimately acquainted. This permits us to think of individuals whom we have known and followed, rather than to rely only on statistical reports of other studies. Over a period of approximately ten years

[4] R. H. Knapp and H. B. Goodrich, *Origins of American Scientists*, U. of Chicago Press, Chicago, 1952.

[5] E. E. Cureton, *Educational Measurement*, American Council on Education, Washington, D. C., 1951.

careful observations and records have been made of more than 400 outstand ing children in the Forest Hills High School in New York. Checks have been made also against the life histories of individual scientists who are personal acquaintances.

Evaluating the role of the genetic factor

In an attempt to determine the relative importanre of the several postulated factors, we find that a lower limit separates those who *might* become creative scientists from those who almost surely will not, no matter what their hopes or perseveranre are. Case studies, growing out of the Forest Hills experiment, of 31 working scientists show that all had, to a considerable degree, both genetic factors: high verbal ability and high mathematical ability. All also had high academic achievement in high school and in college science courses.

Common observation reveals that not all youngsters with high I.Q. scores and high verbal and mathematical scores choose science as a vocation. This is all to the good, for we need competent people in all areas of human activity. Some tenth graders have no interest in science; how this came about is not known, but it would be interesting to explore. Others who seem interested in science in the tenth grade do not have this interest sustained; other areas of study are competing for their interests. The genetic factors, as we have defined them, are a necessary but obviously insufficient condition for selection of a career in science. What, then, is the lower limit of these genetic factors which separates the "possibles" from the "improbables"?

More than 400 ninth-grade students with the highest academic achievement (averages of A, or over 90%) were tested for I.Q., reading comprehension, and arithmetic ability. More than 90 per cent of these were in the upper 10 per cent of the school's distribution of scores on the tests. Forty per cent of these youngsters had I.Q. scores above 140, reading scores of 15, and arithmetic scores of 12 or higher.

These youngsters all took a series of tests of the Psychological Corporation, as well as Thurstone's Tests of Primary Mental Abilities, Form A (ages 11-17), in which the subtests were: Verbal Meaning; Reasoning; Number and Word Fluency. All 400 students scored on both series above the national median. Of those now engaged in scientific research (59 students) all but one scored at the 90th percentile or higher.

All of the 59 students now known to be doing scientific research had I.Q.'s of 135 or above [4] and minimum reading and mathematics scores of 15 years and 12 years respectively in the ninth grade. All subsequently achieved grades of 93 per rent or higher in their science and mathematics courses.

From these data, which have considerable "fare validity," a *base level* of the genetic factor can be set operationally at I.Q. score 135, ninth-grade reading

[4] P. A. Witty and S. Bloom, "Education of the Gifted," *School and Society, 78*, 1953, pp. 113-19, cite a lower level of I.Q. at 130 for "gifted children."

Case Study 1

Summary of a Typical Case Study: High School Student Rated 4 5 on the Scale of Predisposing Factors (disguised slightly)

Male, 11th grade, 15 years

Splendid attendance record (absent 4 days in high school career)

I Q 153, reading score 16 plus (9th year), arithmetic score 12 plus (9th year)

Scholastic average 95 6

Intends to take science, mathematics, language 4 years

Plans to go to Harvard, M I.T , or Princeton

Extracurricular activities· Engineering Club, Research Club, Social Studies Honor Society, Science-Math Honor Society, fencing, school newspaper

President of general recitation classes, and of one club

Hobbies chess, piano, reading, biking (Boy Scouts), woodworking

Works weekends in pharmacy—deliveries

Pleasant yet hurried, never thinks of himself, cannot say no, takes on activities on own initiative, always bemoaning lack of time. refuses to pity himself for any misfortune, high ambitions for public service, high sense of responsibility and integrity, a leader in scholarship, respected by his classmates, shy, great affection for father. Learning to accept himself and environment

Ambition: Research physicist

Case Study 2

Summary of a Typical Case Study: High School Student Rated 3 minus on the Scale of Predisposing Factors (disguised slightly)

Male, 11th grade, 16 years

Good attendance record (average 4 days' absence each year)

I.Q 151, reading score 16 plus (9th year), arithmetic score 12 plus (9th year)

Scholastic average 89 6

Intends to take science, mathematics, language (4 years)

Plans on Harvard, Michigan, or Cornell

Extracurricular activities: Tropical Fish Club, Research Club, school newspaper

Hobbies and after-school activities: baseball, basketball, social club, orchestra, tennis

Does not work after school. Often does not do homework (says he knows his "subjects" without doing it)

Pleasant, loquacious, likes to pass time of day, willing to serve but has to be asked, popular with students and teachers, a great organizer of parties and group activities (almost always takes on collection of dues, etc.), makes friends easily

Ambition: Dentistry, medicine, or science writing

SCALE	0	1	2	3	4	5
Item 6 *Scholastic average* † (*in all subjects through 7th term, includes 3½ years of a full academic program*)	below 86	86-88	88-90	90-92	92-95	over 95 (first 4 of graduating class)
Item 7 *Nature of reading* (*reported in interview*)	little	news papers	school assignments	novels, mainly modern	novels, modern and classic, plus history	novels, modern and classic, plus philosophy, etc.
Item 8 *Type of personal history*		average (like case study of student with I Q 105, scholastic average 75-80)		like Case Study 2		like Case Study 1
Item 9 *Ambition, or drive*	"lazy"			normal ambition but gets over disappointments readily		intense desire to get ahead; does not get over disappointment readily
Item 10 *Tendency to ask questions*	rarely asks questions; accepts information			asks questions when stimulated by information given by others		readily asks questions, often quite original, insatiably curious
SCALE	0	1	2	3	4	5

† Scholastic average is, of course, a frail thing subject to all the errors of the teaching invention (see Section IV)

ninth grade) and 12 plus in a standard arithmetic test. The basic difference between the two members of a pair was *not* the genetic factor (or socio-economic background) or vocational commitment. On the scale of predisposing factors each one in the experimental group had an average score of 1.5 or more, while those in the control group averaged 3 or less. Their observable behavior was clearly different

It seemed useful to assume that those with both high genetic and predisposing factors as defined here would tend to be successful in the modern competitive endeavor of science, judgments could be based on success in college, admission to graduate school, granting of fellowships and assistantships, and success in research.

Clearly, or so it seems to us, a high attendance record, a high rating in item 3, for example, and a history like that detailed in Case Study 1 mean a high emotional commitment.

Evaluating the role of the activating factor

We have been able to observe and study 82 teachers [10] who were apparently successful in stimulating science-prone students to do creative work and to commit themselves to science. In addition, we knew 22 of them personally, and so knew more about them. Their major characteristics were these:

1. More than 90 per cent of the 82 (65 men, 17 women) had a master's degree in science, in addition to the requisite work in education. They were exceptionally well versed in the subject matter of science.

2. More than 50 per cent of them had at one time or another matriculated for a doctorate in science or in education. There were eleven Ph.D.'s (six in science and five in education).

3. More than 50 per cent of them had taught in college (liberal arts or in schools of education) at one time or another. This varied from full time teaching to one or more courses during the week.

4. More than 90 per cent of them had published at least one paper in science or in education.

5. All but one had been an officer in a local or national organization of teachers.

6. All had, at one time or another, been members of a committee to formulate the courses of study or a curriculum for the school district or township in which they taught.

7. All were in general good health and had remarkably high attendance records; very rarely were they out of school for reasons of personal illness.

8. All of the 82 participated in extracurricular activities; not only did these include science work, but work in music, publications, athletics, and so forth. (The 22 who were observed directly often gave up lunch and some

[10] See P. F. Brandwein, *The Gifted Student as Future Scientist*, Harcourt, Brace, N. Y., 1955, pp. 63-65, for the criteria upon which these teachers were selected.

evenings to work with students. They often came to school long before their first class to meet with students or to prepare for special work with them.)

9. The average age of the 82 was 40 years, plus or minus 2. The "plus or minus 2" is necessary, since in a number of cases the exact age could not be ascertained. (Of the 22 known personally the average age at the time of observation was 39.2 years.)

10. The 22 whom we knew personally were expert in hobbies which ranged from chess to collecting antiques. All of these had some regular athletic activity—walking, tennis, gymnastics, handball, or baseball.

11. The 22 were invariably vigorous in their personal manner and, in our judgment, were people of decisiveness.

12. Twenty of the 22 were considered to possess a sense of humor.

13. We would judge eight of the 22 observed teaching (in public and private schools) as outstanding and inspiring master teachers, ten as superior teachers, four as average. The 18 superior or outstanding teachers were dynamic personalities both in classroom and extracurricular activity. Of these 18, 17 were experts in discussion techniques, and their classrooms were centers of student activity; they rarely lectured. One lectured in a private school. All were splendid demonstrators and experimenters; they had at one time or another given demonstrations before teachers' groups.

14. All 22, however, were dissatisfied in one way or another with their progress in teaching, with the state of knowledge of the learning process, and with the professional status of teachers. All 22 were in some way (committees, officers of associations, editors of journals) associated with at least one effort to improve instruction.

15. All 22 liked children. All were vitally interested in science and in other intellectual pursuits.

16. We could not fail to note that these teachers were in the relation of the "father" or "mother" image to the youngsters who were interviewed. These teachers were, in short, not only admired and respected as teachers of subject matter, but as teachers in the ways of life. They were guides, counselors, friends, guardians, and father- or mother-surrogates.

Aside from this, it was very clear that they held up to their students firm standards of competence in scholarship as well as in behavior. In brief, there seemed to be an element of accepted "coercion" (since it was accompanied by sympathetic, even warm, treatment by the student, without fear or threat of punishment). Knapp and Goodrich have amplified the point in their work, *Origins of American Scientists*.[11] A distinctly personal impression remains that these teachers were first of all fine human beings; on the whole they were sensitive to human problems, they were considerate of others, and they were plucky in the face of the frustrations teachers must undergo. They had considerable respect for the goals and the dreams of boys and girls.

[11] R. H. Knapp and H. B. Goodrich, *op. cit.*, p. 170.

TABLE 9-2 *Observable characteristics of able students vocationally interested in science compared with equally able students not vocationally interested in science*

Thirty able students with vocational interest in science ("experimentals")	*Thirty equally able age mates without science vocational interests ("controls")*
1. Outside school the majority tended to individual sports: tennis, cycling, fencing, walking. Very few in team sports: basketball, baseball, football	1. General involvement in team sports as well as individual sports. Most of the boys mentioned football, basketball, the girls mentioned tennis, dancing, etc.
2. A major part of the time spent in reading and other intellectual activities, homework, listening to music, school club activities. Minor, although significant, amount of time in social activities such as dancing	2. A major part of the time spent in social activities: dancing, parties, theater, movies, group activities. A minor, although significant, amount of time spent in homework.
3. A major part of time in self initiated, individual projects: astronomy, "ham radio," stamp collecting, classical music, learning foreign languages or musical instruments	3. Relatively minor part of time spent in self initiated projects of sort described opposite. Tendency to group activity.
4. Tendency to classical music, chess, bridge, and serious reading of classics; do crossword puzzles and acrostics	4. Tendency to popular music, dancing magazine reading, popular novels. Less tendency to crossword and other types of puzzles.
5. Tendency to read "serious" magazines, e.g., *Harper's*, *Time*, *Scientific American*, *Saturday Review*.	5. Tendency to read story type magazines, e.g., *Reader's Digest*, *Saturday Evening Post*
6. A tendency to go to movies less than once a week. Tendency to go to the theater.	6. A tendency to go to movies more than once a week. Prefer movies to theater.
7. Activities joined in school more of discussion type: Language Society, Problems of Civilization, Science, Chemistry Club, school paper, school magazine	7. Clubs joined in school more of "doing" type: Glee Club, Orchestra, Intramurals, school paper, school magazine.
8. Approximately equal (to column 2) tendency to earn extra money in after-school work, but mainly in baby sitting	8. Approximately equal (to column 1) tendency to earn extra money in after school work, baby sitting, delivering newspapers
9. Strong tendency to do social service work, e.g., read to blind, collect for Red Cross, church activity, Civil Defense	9. A minority tend to be in Boy Scouts or Girl Scouts, church activity.

Characteristic behavior of science-prone students

In general there was one personality characteristic of the "gifted student" in science which seemed most obvious. The youngsters in the experimental 62 as compared with the "norm" of behavior at Forest Hills High School might be said to be more quiet, more reflective, more inward-looking; in short, they exhibited, generally, a tendency to introversion. Twenty boys and ten girls, who had the genetic and predisposing factors (previously described among the experimental 62), who were also at the 90th percentile and above in the Primary Mental Abilities and Psychological Corporation tests, and who, in addi-

Note. For other descriptions of the characteristics of gifted children in science, see:
Meister, Morris, in *The Gifted Child*, ed. by Paul Witty, Boston: Heath, 1951.
Subarsky, Zachariah, "What Is Science Talent?" *Scientific Monthly, 66,* 5, May 1948.
Terman, Lewis M., *et al*, *Genetic Studies of Genius*, Stanford, Cal.: Stanford University Press, 1925-47, 4 vols.

Thirty able students with vocational interest in science ("experimentals")	*Thirty equally able age mates without science vocational interests ("controls")*
10. Tend to be conservative in clothing, although within norm, e.g., most boys wear ties, rarely take on "fads."	10. A goodly number (not over 50 per cent of the group, however) take on "fads," of teen-agers, e.g., plaid shirts, jeans, etc.
11. Vast majority buy books for personal library.	11. Only a minority buy books for personal library.
12. Tend not to smoke till senior year, or not at all.	12. Tend to smoke early.
13. All plan to go to college	13. Most plan to go to college; some plan to go into business, minority into professional life.
14. Almost never get into difficulty with teachers or are disciplinary problems in school over school work. May disagree with teachers over interpretation of subject matter.	14. Almost never get into difficulty with teachers over school work or are disciplinary problems in school. May disagree with teachers over interpretation of subject matter.
15. Almost all the parents had a post-high school education. More than half were graduates of colleges: a high number of graduate schools (Ph.D., M.D., Law, Engineering, Accounting). A high minority in professions.	15. Almost all parents had a post-high school education, with a high majority in business. Slightly more than one-fourth were graduates of colleges, a number in medicine and engineering.
16. A tendency for parents to own a substantial library (500 books or more). A vast majority with 200 books or more.*	16. A minority with parents having a substantial library; most with less than 200 books.
17. Vast majority of parents with ambitions for professional life for their children	17. Vast majority of parents with ambitions for financial success for their children.
18. Average of children per family, 1.2.	18. Average of children per family, 2.4.
19. Twenty-four of the 30 were the first child, 16 were the only child.	19. Eleven of the 30 were the first child.

* This seems as if it were an overestimation, but for the students we observed it was generally true.

tion, had placed as one of the fifty finalists (8) or had won honorable mention (22) in the Westinghouse Science Talent Search, were compared with their age mates (a type of control) who were not committed to science vocationally although they were very successful in high school in other areas. These age mates were of similar socio-economic level, and although paired with the experimentals for genetic factors, were *not* so paired for predisposing factors. The purpose of this was to obtain a trend or *tendency* [11] in behavior of these youngsters who had committed themselves to science. A comparison of behaviors observed is shown in Table 9-2.

[11] Information obtained through interview. The word *tendency* describes an activity of more than 50 per cent of the group.

From these observations, a picture, admittedly with hazy outlines, may be formed of these youngsters who may be our "scientists-in-embryo." It seems possible that the high rating in predisposing factors of the experimental 62 is related to their introversion (as indicated in the tabular description) MacCurdy's[13] study of the characteristics of superior science students (Westinghouse Science Talent Search winners) extends over a greater area of the background of these youngsters than does the description tabulated below. Nevertheless, there is essential agreement on the major points made. Terman,[14] whose studies on the general nature of giftedness are classic, wrote (on the basis of a study of 800 gifted males now committed to the sciences, humanities, social sciences, and business, among other fields):

> At any rate, in our gifted group the physical scientists and engineers are at the opposite pole from the businessmen and lawyers in abilities, in occupational interests, and in social behavior.

A curious observation bearing on item 19, Table 9-2, deserves comment. Of the 59 students known to be doing scientific research 35 were the only children in the family, and 21 were first children. How significant is this? How general is it?

As more investigations of the type A. Roe and L. Kubie[15] are doing on the adult level are duplicated on the high school level, we shall know more about the individual characteristics of these scientists-to-be. Hence, the observations described here must be considered tentative.

In Chapter 6, Winning the Concept, we have described one way of work of these youngsters. We found them to fit that notion of thinking, inventing, investigating which we called the "Eureka." Or perhaps we should say observations of their method of work helped us attain the concept of the Eureka. Nothing new, of course; it is only that the Eureka hypothesis helped us understand the way these youngsters work and enabled us to develop the physical environment in which they could work with greater ease. The stages of Exploration, Incubation, and Illumination (described on p. 119) are clearly recognizable in the processes of investigation of these youngsters, although the stages do overlap.

A general base in curricular policy for the science prone

A course in science is one in which students, having had a course in the history of biological science (now known as biology), proceed to deal with the science of biology. Here they agonize over new relationships: they try to do something new; they get small problems, even trivial ones (although this isn't

[13] R. D. MacCurdy, "Characteristics of Superior Science Students and Some Factors That Were Found in Their Background," Ed D Dissertation, Boston University, 1954.

[14] L. M. Terman, "Are Scientists Different?" *Scientific American*, 29, Jan 1955, also, *Scientists and Nonscientists in a Group of 800 Gifted Men*, Psychological Monographs, Vol. 68, No 378, 1954.

[15] *Op cit.*, p. 169.

necessary; they may even be good problems), but problems beyond the known. The text becomes a base of operations, a place to jump off into the future. Students do "research" and, in so doing, "wet their feet" in science.

Certainly if Music Departments permit or urge their best students to become creative early (to create music), if Physical Education Departments permit their best to become prize athletes at the earliest opportunity, and if Art Departments encourage their best to create as soon as they dare, Science Departments and Mathematics Departments may permit their best students to create early; in short, to do science and do it before graduate school or the senior years in college or even the senior years in high school.

Correlating with this acceleration is the acceptance by teachers of the idea that science and mathematics do not mean merely study and review of the past. More important in facing problems which must be solved by some aspect of originality is the acceptance of another idea: equal opportunity does not mean identical exposure but rather equal opportunity to develop to one's fullest potential. Carried into practice this would mean making special opportunities available for *all* students, *including the science prone, the gifted;* carried into educational thinking it would mean simply applying the general principle of variability to the intellectual domain, as well as to the physical.

In other words, stimulating the scienre prone by giving them the opportunity to develop to their fullest does *not* mean giving them more course work, or intensifying the accumulation of information through lecture and text; it does *not* mean *covering* more material, but rather *uncovering* it through the best teaching procedure. The teacher should, in other words, "teach less so that the learner may learn more."

These two notions are basic:

1. Science and mathematics do not mean merely a study of *past* science and mathematics, but an opportunity to invent, to imagine, to discover, to aspire, sometimes to succeed, but sometimes to fail in a worthy quest.

2. Equal opportunity in education means the opportunity for each to develop his abilities to the fullest; it does not necessarily mean identical programing.

Many groups are deeply concerned about providing more effective instruction for the most able students. All too often these students have been caught in the "single" program aimed at the "average" student. Within such narrow confines they have become bored and sometimes bothersome. Perhaps worst of all, they develop poor work habits; for "getting by" (even getting high grades) is easy for them.

Despite growing concern by governmental, scientific, and industrial leaders, some educators seem nervous and continually wonder whether special attention to the able is "democratic." As we have outlined above, the basic concept of democratic education is ***equal opportunity***, not identical exposure, for all. Gowan [14] states: "A recent California study showed parents far more

[14] J. C. Gowan and M. S. Gowan, *1956 Addition to Annotated Bibliography of Education of Gifted Children*, University of California at Los Angeles, 1957.

liberal in their attitudes toward education for the gifted than principals and supervisors in public schools." Then it may be hoped that within the next decades more will be done for the abler students; the public will demand it. Equally important is the choice of teachers and procedures based on clear evidence.

The choice of curricular method depends on many factors: the nature of the community, the philosophy, traditions, and preparation of the staff, the nature and destination of the student population and the faculty; the convictions of administrative and guidance workers. Throughout the country, curricular practices seem to be taking these directions.

The advanced course. This course may be identified as biology, physics, or chemistry, but it goes beyond the high school curriculum (as evidenced in texts and syllabuses), into what is recognizably college work. Sometimes the course is a replica of a college course in a nearby university which accepts most of the students of the high school. The students in these courses are selected on the base of I.Q. (usually a lower base of 120-130) and previous achievement (they are in the first quartile of their classes). In most high schools these courses are first available in the sophomore (tenth) grade; freshman courses (ninth grade) are not available except when the high school includes the seventh, eighth, and ninth years. Sometimes these courses are called honor courses, and usually consist of the established courses *plus more work*. The "truly" advanced course consists of *more advanced work*.[17]

The special course. This course is organized for special work. Students who take the course have generally taken the established curriculum, or are taking this course concurrently with the established curriculum. Such a course might be Advanced Science,[18] a course extending throughout the high school years, in which students work on their own "original" projects in the laboratory as embryonic scientists. Or a course in mathematical analysis or the calculus may be given. In any event, either students are carefully selected for such courses, or they select themselves because of their expressed vocational interest. Courses like these are usually found in large high schools where the population permits wider diversification of courses.

The special group. In many schools, large or small, there are no special courses, but special groups; this procedure is especially well-suited for the small schools. These groups meet when possible, and when a teacher is available, before, during, or after school. They are usually organized as clubs, but

[17] R. J. Havighurst *et al., A Survey of the Education of Gifted Children*, U. of Chicago Press, Chicago, 1955.
Harry Passow *et al., Planning for Talented Youth*, Bureau of Publications, Teachers College, Columbia University, N. Y., 1955.
American Association for Gifted Children, *The Gifted Child*, ed. by Paul Witty, Heath, Boston, 1951.
School and College Study of Admission with Advanced Standing, *College Admission with Advanced Standing Bulletin of Information*, William H. Cornog, Executive Director, % Central High School, Philadelphia, 1954, now at New Trier Twp. High School, Illinois.
[18] Chapter 3, Science Classes.

may be organized as classes. The number of students involved may range from one to several hundred.

Whether they be called The Camera Club, Engineering Society, Chemistry Squad, The Physicists, The Geometers, The Calculus Society, The Biology Club, The Math Club, or Junior Scientists, these groups or clubs are concerned with learning more about science and mathematics.[19] Four kinds of groups are discernible:

1. The "hobby" group: Here boys and girls interested in radio or tropical fish or field trips or snakes or photography gather to *explore* and *exploit* mutual interests. Some of these youngsters may be science prone.

2. The "scholars" group: Boys and girls are gathered here to *extend* an experience, to delve deeper into a field of study. The Calculus Society goes into the calculus; one sees a systematic attempt to learn *more* in an organized way. These are courses, as it were, after school. In this way in several small and large schools we have seen intensive courses on the collegiate level in botany, zoology, chemistry, physics, calculus.

3. The "seminar" group: Groups organized in this fashion are given over to hearing the latest advances in the area. Here especially scientists in the local university, college, or industries lend a hand to *stimulate* young scientists-to-be or young mathematicians-to-be. Such a group is often called the Young Scientists, or the Science-Mathematics Seminar. This grouping is an attempt to enrich the science work, particularly in small schools. These groups generally sponsor a Science Fair where young people exhibit their project work.

4. The "vocational" group: While all the groups mentioned above usually seek information about future work in science or mathematics, these are special groups (mainly concerned with vocational guidance) which are concerned at times with stimulating gifted children to enter science. These may meet irregularly, particularly to hear a scientist, an engineer, a mathematician, a doctor, or some such person discuss the vocation in question.

The "advanced school." Even before the Advanced School Study of the Ford Foundation was instituted, a number of schools had developed what they called Honor Schools or Advanced Schools within the organization of the regular high school.[20] These Advanced Schools (schools within a school, with their own administrators) selected youngsters on the basis of high I.Q., general high achievement in major courses (English, social studies, mathematics, and science; sometimes language), and aimed the course work at a higher level than that expected of the general school population.

Sometimes as part of the Advanced School Study these schools gave the equivalent of "college" work in the subject areas where there were qualified

[19] G. L. Loomis, "Special Provision for the Gifted," in *A Survey of Literature and Research Concerning the Education of the Gifted Child with Implications for School Practice*, Curriculum Bulletin No. 97, Eugene, Ore., School of Education, 1951, pp. 10-23.

[20] School and College Study of Admission with Advanced Standing, *op. cit.*

instructional staff and equipment. Students who qualified in the Advanced School Study examinations could be admitted to college with advanced standing in the special courses for which they qualified.[21]

The special school. In large cities, particularly New York City, specialized high schools, such as the Bronx High School of Science, Stuyvesant High School, Brooklyn Technical High School, and High School of Music and Art, select students with high I.Q.'s and "special" abilities for advanced work. For instance, the Bronx High School of Science selects youngsters with high I.Q.'s and high verbal and mathematical abilities and gives them an enriched four years in a regular high school curriculum intended for admission to college and, in addition, enriched and advanced courses in science and mathematics.[22]

The independent school. There are also private secondary schools, often having high standards of selection. Many of these give advanced work in science and mathematics. For instance, in one such school we observed courses in organic chemistry and the calculus.

Some practices in small schools. Many schools are too small to organize special groups. In such schools, we have observed special efforts being made even for *one* gifted student: special tutoring in certain course work (whether standard or advanced), the practice of apprenticing the student to an interested industrial or university scientist (either during the regular session or during the summer session), and, if nothing else, suggested readings and conferences. And in many cases these are extremely effective because usually the gifted student reacts catalytically to the personal interest shown and the guidance offered.

A general base in method for the science prone

In essence, the teacher is the key to successful work with the gifted. A teacher who has high standards but is not coercive, who is firm but not dominating, who is sympathetic and friendly, whom the student will accept as surrogate parent, does much to nurture giftedness. Such a teacher may or may not be an "expert" in the area (as technical expertness is defined), but he must be an expert teacher and an expert at being human. He knows that teaching is a personal invention and he is constantly at work improving his invention.

Such a teacher knows that, while the history of science and of mathematics is *taught*, science and mathematics are *done*. Whether they are done within the "course" or during a separate time is not significant. Both types

[21] G. I. Loomis, *op cit*, pp 10 23.

[22] Board of Education of the City of New York, *Specialized High Schools in New York City*, Brooklyn, 1946, 263 pp.

of organization have been observed in several schools. The basic postulate is that young scientists and mathematicians are developed best when they *do* science and mathematics, not when they are held fast in the bonds of the past.

The stress, then, in teaching the "gifted" or "rapid learner," as indeed it is in teaching the "slow learner" or for that matter any student, is on *gifted teaching*. What is the general base in method which the best kind of teaching stresses?

The type of teaching of which we speak is based on the curricular principle we have stressed, it may be restated this way: All living things have certain similarities; however, in developing youngsters to their fullest it is the *differences* which must be cherished. It is these differences which are responsible for the essential differences in creativeness. Hence, teaching to stimulate creativeness, or originality, is teaching which honors differences, and which is differentiated in its method. Teachers who honor difference generally are involved in some or all of these activities.

Knowledge of differences. Teachers who cared about individual differences usually had a good idea of the kinds of children in their classes. They had examined the records of their students, including I.Q., reading score, and mathematics score. Or they were using the recording devices, or something similar, to be found in *Identifying Students with Special Needs*.[13] They had, therefore, an idea who was who: who was gifted, who was slower.

Differentiated seating. Some teachers observed used the interesting device of differentiated (not segregated) seating. At the beginning they seated in groups of four or eight, for ease in group or committee work, children of *different* intellectual potential; this gave different students the opportunity to exert leadership at different times; at various times the bright child had an opportunity to exert leadership. Also it strengthened his knowledge of subject matter since at times he accepted the role of tutor.

Differentiated assignments. One of the most common approaches was the differentiated assignment. Different problems varying from simple to most complex were offered as challenges; different and more complex science readings, "experiments," and devices were suggested. Particularly was this practice used under the guise of "honor problems" in genetics, chemistry, physics, astronomy. The prize was a college text in science for the one who solved selected problems correctly. The nature of the prize was determined by students who also served as the prize committee. In addition, senior students developed the problems for junior students.

Differentiated texts. In a good number of the classrooms observed, different texts were used for the more rapid learners. In one case, the students received an additional, more advanced text when they finished the first, and

[13] R. F. DeHaan, and J. Kough, *Identifying Students with Special Needs*, 2nd ed., Vol. 1, Science Research Associates, Chicago, 1956

honor credit was given for evidence of finishing the second. In another case, a college text was used. In still another case, the teacher used the much-maligned workbook as a guide for study: different students used different texts as references to serve them in doing the "exercises" suggested in the workbook, the rapid learners used college texts.

Differentiated laboratory work. Naturally, the laboratory is the place where each student can work at his own speed, and the able can exceed the work expected of others. This is also a place where he can originate. In a large number of classes observed, teachers who were interested in stimulating the gifted permitted them to go beyond the "required" exercise where a workbook was used, to attempt their own "experimentation" after the required work was done, or to undertake their own "experimentation" in place of the required work (provided a plan of such experimentation was submitted to the teacher for approval prior to the laboratory period).

In mathematics, the practice was quite common to permit students to prepare their own problems which were then posted for class evaluation and solution. In addition, "laboratory" periods were scheduled in which youngsters applied their mathematics to the solution of industrial and engineering problems.

Differentiated tests. In one school, a somewhat unusual kind of test was used which permitted the greatest scope for all, but was especially useful in identifying and sustaining the rapid learner. (See Chapter 20, An Approach to Test Building and Interpretation, for an example of this test.)

Assume that the students in a chemistry course have finished a unit on atomic energy. The examination is made up of some two hundred short answer (multiple choice) items on six sheets; only the top sheet (50 items) is concerned with atomic energy. Each correct answer brings the student two credits; total: $2 \times 50 = 100$.

When the students have finished all 50 items in the test on atomic energy, they may go on to the other items on the remaining five pages. These items are concerned with content which covers the entire term's work and goes beyond the term's work into special readings (magazines, college texts, library work). For each item chosen and answered correctly, the student gets one point credit; for each one chosen and missed, two points lost (this last discourages guessing). The net result is that students can get total credits beyond one hundred, *if they know more*. A student who averages above one hundred is entitled to very special recommendations to college and special privileges, e.g., use of the laboratory for individual work.

Apparently students favor tests of this kind which reward them for knowing more than the required work. Such tests seem to be excellent predictors of success in college and in special competitive science examinations (Westinghouse Science Talent Search, National Merit Scholarships, etc.). Although this test form was devised for science classes, it could be used in any subject to reward those who know more than was taken up in the course, or who learn it earlier than required.

A case study of an approach to teaching the science prone

A standard or ready-made procedure for teaching the science prone would surely be useful. Yet classes and schools, teachers and pupils differ, and each combination is an opportunity for creation of a personal invention fitting the local conditions. If the student is science prone, his learning is easier; but his teaching is more exacting.

We have heard teachers say that the bright or able child can get along on his own, and that class time should be centered primarily on the normal or slow students. This is grossly wrong. Able students are precious and rare, and of high potential value to their culture. They quickly form concepts—incorrect as well as correct ones. Through their teaching they must learn how to sift and test concepts so that they can hold the useful ones and discard the not-useful.

Perhaps the most serious consequence of neglecting these children is to permit them to develop poor work habits and a "swelled head." They must be held to high standards of expectation and performance and aided in developing the inner controls and responsibility that will bring their *potential ability into productive ability.*

What do you teach these children? How do you teach them? In groups? Individually? You may find clues in the following case study in teaching the science prone.

For the science prone, materials are to be *uncovered*, not *covered*. For these able youngsters the teacher must reaffirm and practice his function as a *guide to learning.*

More than any others, the boys and girls in this group have high educational irritability; they are sensitive to the world and to learning. Once they notice something they want, they do all they can to get it. These four guides to learning—young people must want something; they must notice something; they must do something; they must get something—constitute almost a single purposive pattern in the science prone. They want to grow; they are always on the *qui vive,* noticing things as they go; they do not hesitate to do, to work; and they get satisfaction in doing and learning. All these youngsters are going concerns (they are motivated, that is); all one has to do is to put enough interesting things before them and they *notice, do,* and *get.* With the science prone, more than with any other group, the curriculum can be said to exist within the child. These boys and girls are intellectually omnivorous; generally they are college oriented.

The science-prone student in class

We have discussed the characteristics of the science prone and the nature of a science program which involves their energies. This may not tell our readers how they differ from others in class. Of course, some of them may *not* be the epitome of the kind of student who is quietly competent, the delight of

honor credit was given for evidence of finishing the second. In another case, a college text was used. In still another case, the teacher used the much maligned workbook as a guide for study, different students used different texts as references to serve them in doing the "exercises" suggested in the workbook; the rapid learners used college texts.

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of moments; he showed a great deal of mathematical ability in solving problems dealing with the law of moments. It turned out that he was primarily interested in mathematics, and the mathematics in physics fascinated him. From then on his record was magnificent. Once his interest was kindled, he involved himself in nonmathematical areas; for instance, he entered the Science Fair and distinguished himself by winning a first prize.

In short, these boys and girls present a different dimension in class work; they not only go *deeper* but often have a *special interest* which gives them direction. This indicates that these boys and girls might with careful handling (i.e., special opportunities as indicated in this chapter; see also Section V, Tools for the Science Teacher) become specialists. To develop specialists, the scientists of the future, one might very well make special opportunities available—even within the pattern and goals of general education.

Furthermore, there is quite a difference, in our minds, between "bright" and "gifted" children, although usage has become somewhat loose. Let us define our terms:

1. Both bright and gifted children have high genetic factors.
2. Bright children do not necessarily have high predisposing factors; their goals may not be sufficiently determined, their attitudes not sufficiently focussed; they may be complacent, easily satisfied.
3. Gifted children have a high predisposing factor in some area.
4. If this area is science, they are science prone.

Gifted students are very rare; they are the contributors-to-be. If they are science prone and truly gifted, they generally become great investigators. While classes composed wholly of gifted students cannot often be organized, classes of very bright children (including some of the science prone) can be organized and taught by the best methods available, the methods delineated in prior chapters. No doubt, because this is the folklore of modern education, teachers will ask: What of the course material? textbooks? syllabus? tests? basis for grades?

These boys and girls can, and should, do more; this includes reading, as well as laboratory and field work. The science prone can use both a high school text and a college text: a high school text for first reading and security, then one or more college texts for an extension of the topics being studied. This is the basic reading material. They will also desire and seek added reference material: *Scientific American*, *The American Scientist*, *Science*, *The Quarterly Review of Biology*, and many others. (See Section V, Tools for the Science Teacher: The Professional Library.)

But in the main, teaching the science prone consists not in a fuller course on the "college level," but in the use of our best knowledge about teaching. Each teacher will develop his own teaching invention, within the framework of his school and community. Perhaps he will find the following case study helpful.

the teacher. Some of them may even be so-called "discipline problems." In such cases, they share with others all the problems of the adolescent. Their intellectual competence and activities—the projects they do, the hobbies they embrace, their after school actions—have been described earlier in the chapter. In class they also differ in their behavior.

Generally, they are very alert, they tend to be volunteers; in fact, the teacher must be careful to keep them from monopolizing the class discussion. He does this by calling on auditors (those who listen passively) as well as volunteers (those who participate actively). In this way teachers not only *cover* the material, they also *uncover* it for auditors as well as the volunteers. Science prone volunteers will not only answer but question as well.

A comparison of their answers and questions with those of their classmates will indicate the range of their intellectual activity. For instance:

Class situation A—general science. The class had been discussing meteors. The class, generally, was offering information which could be found in the textbook. One student, however, offered information which he had gathered from attendance at the meetings of the local chapter of an association of astronomers. Furthermore, he had made observations of meteor showers. He had been doing *extra* work even before the topic had been brought up. (This kind of activity indicates more than anything else the nature of the commitment of the science-prone student.)

Class situation B—biology. The class had been discussing enzymes. The teacher had demonstrated gastric digestion (first day), and the class had done a laboratory exercise on salivary digestion (second day). Now the class was developing the concept of enzyme action. The discussion had centered around "digestion." One girl asked, "Don't enzymes act on other functions, like respiration? It seems to me I have heard about respiratory enzymes." With careful questioning by the teacher, the girl admitted that her uncle was a doctor and she had been reading some of his books. She "knew" something of the functions of the vitamin B complex in forming the various respiratory enzymes (particularly Warburg's yellow enzyme). She volunteered to share her information with the class in a report. (Such youngsters not only do more, they read more and learn more.)

Class situation C—chemistry. The class had been studying the postulated conversion of hydrogen into helium in the sun. To simplify matters, the teacher had accepted the idea, as expressed by the students, that the conversion consisted of the combination of hydrogen nuclei. One of the boys, usually quiet, offered the information that Bethe's notion involved the combination of the hydrogen nucleus with carbon, then isotopes of nitrogen and oxygen were involved, and finally helium was formed. He gave a tightly knit account of the process. Apparently this was an area in which he had been interested; the rest of chemistry was not as exciting. (The science prone sometime show a great selectiveness in the areas to which they commit themselves.)

Class situation D—physics. One boy, with a mediocre record (C) up to this point (the middle of the term), suddenly blossomed during the discussion

work. This work should not be considered extracurricular ("outside the curriculum") but an integral part of school work in any science training program.

The students go on to a second year of science work. Among the many factors responsible for this continuing study, two are especially important: the sympathetic viewpoint of the administrative officers and the guidance department of the school toward the study of science, and the favored economic position, in general, of the student body. But also the wide variety of available science activities invites the extension of almost any interest.

Toward the end of the second term in general science, students selected (on the basis of I.Q. tests, reading scores, mathematics scores, junior high school grades, and our own observation in the first term of high school general science) are given the opportunity to enter a so-called Science-Math Honor Class or classes. Very few decline the offer. Out of 400 who entered together as a ninth-grade class, some 40 to 70 find themselves in this group. Those students whose course programing difficulties make it impossible for them to enter the honor classes are nevertheless given opportunities for similar work.

In the honor class these students enter upon three years of enriched science and three years of enriched mathematics for a total of four years each of both science and mathematics. Generally, students of the highest caliber are found in this class, among them are the students who are in the first quartile of their graduating class. Regularly, the first ten in over-all scholastic standing are to be found in these honor classes.

Several purposes are served by having these students in such classes. They are given a different course of greater difficulty, of more advanced material. They are capable of attaining a high appreciation of scientific methods and their social implications. They are given work which stimulates them to develop high efficiency in the laboratory and field. More important than these, perhaps, is that considerable time is spent in personal guidance, so that the opportunities and advantages of entering fields of science are opened to them.

Thus, while 70 to 75 per cent of the student body is taking science work each term (many of the students not in honor classes also elect four years of science), approximately 200 to 240 students are in this special science program.[24] Are we justified in making this selection? (Note that the selection is not made on the basis of grades alone: we have permitted students with over-all scholastic averages of 80 to 85% to enter this classification and have given them the same training: the student with an intense hobby, such as radio or the collection of insects, is also selected, regardless of his grades.) Whether we are justified depends on the data we will gather from the future achievements of these students in collegiate and postcollegiate work. Every student is *given the opportunity* to show his ability and avail himself of special training, but

[24] Of course, some students who enter the program drop out along the way; we have found, however, that more enter the program later, so that there are always more students in this program by the senior year than there were originally.

Let us follow an entering freshman class (ninth grade) of approximately 400 students at the Forest Hills High School.[24] All of these ninth grade students take a course in general science. This is designed to further understanding of the common phenomena in their environment, the areas of life and living which science might help to solve, such as the use of natural resources, the use of energy for doing the world's work, the problem of getting along with other men, and the conquest of disease. The first step in selecting and training the prospective scientist occurs here.

The progress of students who show any signs of distinguishing themselves in science is noted during the first few months of the course. Attention is given not only to the gifted students, but also to those who show an ability to work with their hands, those who may have a "hobby" interest in science even if their science grades are not particularly distinguished. These first distinctions are deliberately vague, for our purpose is to give each student the environment which will enable him to make the utmost use of his gifts and opportunities.

At the end of the first term, those who have shown interest as well as ability to work in science are given an opportunity to work in the laboratories during their free periods before, during, and after school.[25] Generally those who are interested ask for this opportunity. Others who have ability, as shown by their work in class, are invited to work; this is part of the self-selection process through equal opportunity. Some of the activities they may choose include the following:

1. Preparing teaching materials in chemistry, physics, or biology.
2. Assisting a science teacher in his field of special interest.
3. Maintaining a large school museum of a wide variety of living and preserved specimens.
4. Maintaining a vivarium of forms particularly useful in biological work. Here students learn to maintain insects and mammals as well as cultures of the common protozoa and algae.
5. Engaging in science work in a variety of activities such as "The Science Journal" and the chemistry, physics, biology, or engineering clubs. They may help make models in the Bio-Arts Club. The Museum Curators, the Science Projects, the Cancer Committee, and the Laboratory Technicians Club offer other opportunities. This club program was purposely made broad, in order to attract and hold those with diverse interests in science.

During the second semester this program of guidance continues. The result is that many good students enter into this so-called extracurricular science

[24] Since the time of this example, the school's enrollment has increased from 1200 to 4000. Now the children enter in the tenth grade. Close cooperation with the feeding schools (elementary and junior high schools) provides the same information previously available through personal observation.

[25] If the ninth grade pupils are in a junior high school, their opportunities for work in large laboratories are less. They might be given the use of the high school laboratories. Even if this is not possible, many of the suggestions listed here can readily be carried through in a junior high school and, with encouragement, at home.

sight to watch young people tackle a scientific problem and, using their intelligence without any outside interference, emerge with a solution.

Where do these young people get their projects? From many sources: consultation with teachers, with college and university scientists, with parents, with research men in industry. One other way we have found very useful, old and new editions of ***Biological Abstracts, Chemical Abstracts,*** and *Physical Abstracts* furnish many ideas. When students write to the author of the particular abstract in which they are interested, they get many suggestions for small projects which they can do on the high school level.[27]

Where do these students get their special equipment? It is not surprising that a school administration and a parents' association will support a good teaching invention. Industry and universities will offer not only advice, but equipment as well. Many teachers throughout the country have found that enormous potential aid exists in the community; all that is needed is a sensible request for a desirable purpose. At times the student, like the scientist, may also be obliged to invent equipment or to organize available materials in a novel manner. The history of science is full of instances where the invention of a new tool or a new procedure was the key to a major question.

Where is the teacher in all this? Generally, a student asks a question because he is confused. To give him an answer would destroy his initiative and make him dependent upon others. Instead of answering, the teacher responds with a "loaded" question which puts him on the right track, provided he uses his brain and other resources, including the library. This requires teachers who know their science thoroughly and have created a rich library with which they are also familiar. They do not give the student answers which he can discover for himself by painstaking effort. The teacher is also constantly aware of progress in the laboratory by looking over shoulders and by evaluating the monthly progress reports which the students submit.

Clearly observable was the nature of the teacher who was "successful" with these young people. Dominating, authoritarian, or laissez-faire, unorganized individuals did not seem to hold these youngsters (Chap. 4). The pattern of the teacher generally successful was as pictured in our Mr. P. (p. 78).

In this advanced science class, the mature scientist could see a picture of the scientist-in-embryo. And this is especially true of the research activity undertaken by these youngsters. In most cases, the student faces a problem he has never faced before. No solution is available in textbooks, and it may take two or more years of work to reach even a tentative conclusion. For instance, do zygospores of *Rhizopus nigricans* germinate? Many textbooks assume such germination. Several students found no such evidence on the basis of their investigation, and they had their conclusions supported by several authorities in the field. How long does digestion take in the food vacuoles of different protozoa? Why does *Chaos chaos* appear to have only a regional distribution? What factors influence sporting in species of *Coleus*? What effect

[27] See also *Thousands of Science Projects*, Science Clubs of America, Science Service, 1719 N Street, N.W., Washington, D. C., 1953.

we have found that those who have average grades of 90% or over are able to take the best advantage of the types of training described in the following list.

The students selected each term are given the opportunity to:

1. Engage in some "original" research work on the high school level. Each student is under the close guidance and observation of a teacher. (This work was mentioned in Chapters 1 and 8.)

2. Learn the expert use and operation of laboratory equipment of all types (analytical balance, microscope, electric oven, autoclave, etc.).

3. Learn laboratory techniques (histological, bacteriological, analytical, work with glass, etc.)

4. Gain special skills in shopwork, including handling of common materials (wood, metal, etc.).

5. Engage in library research, including college texts in biology, physics, and chemistry, and other pertinent materials.

6. Take adequate training in mathematics.

7. Prepare exhibits of their work for demonstration before other students, at science fairs or local exhibitions.

8. Prepare, in their senior year, written reports of their work for the school science journal or for other journals.

9. Engage in seminar activity at regular meetings of the school Science and Mathematics Honor Society. Students who have shown competence in science are eligible for election to the Society. Students who offer the best reports of their work will in turn be invited to submit that work at a Biology Congress sponsored by the New York Association of Biology Teachers or to exhibit their projects at the Science Fair sponsored by the Federation of Science Teachers Association of New York.

10. Engage, as seniors, in the Annual Science Talent Search of the Westinghouse Educational Foundation.

This is the *training method* for selecting science-talented students as opposed to the *testing method*. The observable behavior of these students at work, rather than the results of any battery of tests, is appraised. This observational method is in its preliminary stage of development, but it is described because it relates to the problem of staffing our science laboratories. From those who do not become research scientists will come, perhaps, highly skilled, reliable technicians.

After the first half year in this honor science math class (usually a biology course), the students who so wish are given the opportunity to enter a scheduled advanced science class. This is actually an additional period of science. However, it is spent not in the classroom but in the laboratory; it is a period where a student may select his own project and solve it in the laboratory. Some students continue these projects at home; many work in the school laboratory before and after the regular school schedules. It is a gratifying

course, there are those who cannot learn to work with others. None of these students are dropped from this special program until repeated attempts have failed to bring desirable changes; some youngsters are retained until the bitter end, especially when their basic qualities warrant it.

By the beginning of the latter half of the senior year there remain perhaps ten boys and girls who have participated in most of the ten activities previously listed. In addition, these students are most skillful in grasping scientific concepts, projecting them, and using them to solve scientific problems. We believe they have the ability to be scientists.

Among these ten senior special science students are the three or four who, we believe, may be the research scientists of the future. These three or four are given further apprentice training in their senior year. They are placed in industrial, college, or research laboratories to assist scientists at work. For such opportunities we are grateful to the many individuals in college and industrial laboratories who have given generously of their time and energy. These students distinguish themselves by winning extensive honors in the various activities sponsored by different organizations.

Forest Hills High School was instituted in 1941. From February 1945, when the first class which had been at the school for four years was graduated, to June 1957, this program yielded 116 students considered to have promise as research scientists. (These include the 59 mentioned on p. 180.) However, approximately 800 other students have been given similar training. While we feel that the 116 are of the caliber to make research scientists, we believe that the 800 may also enter the scientific field and achieve a measure of success. Although we do not predict the same kind of success for them as for the 116, we shall check our predictions against the actuality. For the present, it will suffice to say that these 116 have achieved distinctively high honors in high school and college, as have many of the 800. The data are still incomplete for a secure evaluation of results.

Grades are easily assigned to students who elect the honors program and do the activities described here. Upon admission into such a course, each student is given a grade of 90%. Surely he could earn this in a "normal" course competing with his less able and less motivated classmates. Thereafter the excellence of his performance determines how much of the residual ten points he is credited with. Failures, which do occur for various reasons, are also easily handled; the youngster is moved back into the "normal" program which is less demanding.

In a small school where special honors classes are impractical, records of additional accomplishments (projects developed, reading completed, mathematical skills developed) can be kept for future reference when colleges or industries inquire about the student. In such small schools we would expect the promising student, if handled effectively, to excel in the regular class work and attain the highest grades. In one small school, youngsters corresponded with scientists, in a large city nearby, who advised them on projects.

does the gas produced by *Tribolium confusum* have on other insects? Other work includes a study of the embryology of *Physa*, diapause in *Cecropia* and other insects, development *in vitro* of certain plant embryos, studies on a modified method useful in the recovery of silver in photography, the structure of soils in the vicinity of the school, studies of aberrant electrostatic effects, meteors, background radiation in the local area, inversion in *Volvox*, sporulation in lager yeast, the influence of sun spots on agriculture, a modified circuit breaker, and various other studies in biology, chemistry, physics, geology, and other fields. There is little doubt in our minds as we observe these young people at work that they are using the methods employed by the professional scientist in his experiments.

And as they work, they grow. They make the scientist's methods of thought their own, at least in regard to the problem at hand. Encouragingly, they feel that these methods hold much promise for use in investigating social as well as natural phenomena.

This early training and emphasis in the social responsibilities of scientists are of the utmost importance. These boys and girls are still plastic. Perhaps if we train our students in high school and even earlier to see themselves as citizens first and specialists later, we shall not have the situation which Dean Harry J. Carman of Columbia University (now retired) described in these terms: "In public life we are ruled by scientific ignoramuses, and in the scientific laboratory we have, for the most part, political and social illiterates." The elimination of this state of affairs is one objective of our program of general and special education.

At the end of the tenth grade we have, then, 40 to 60 youngsters who are ready and willing to embark on an extended period of work. Each day for the next two years, they have one period of science, one period of mathematics, and one period of laboratory work on a personal project, if they wish it. Those who do not work on projects in school (and some who do) generally work at home. In doing their personal project work these students must read source material, plan experiments, order materials, construct equipment—in short, over a period of two and a half years, carry out in a small way the methods which serve the scientist. Their teachers are ready to advise them, but advice is forthcoming only when the problem presented is worthy of consideration by the sponsor and is not indicative of laziness, poor thinking, or poor working method. In the case of the latter, the student is given whatever guidance is advisable and turned back to his work.

During the following two year period (junior senior) many students drop out of the program. Some find that athletics and social events are more important to them than science; others are not fitted, through lack of even the simplest manual skills, to carry on the work; still others lack originality. Those few lacking in honesty or a sense of responsibility are first guided by the sponsor, who attempts to produce changes in attitude; if repeated attempts fail, the student is advised by the sponsor to seek other work. And, of

the National Science Teachers Association, 1201 16th St., N.W., Washington 6, D. C.

9-3. Have you read the *Occupations Handbook* of the U. S. Bureau of Labor Statistics? If you are already teaching, do you keep a card file of sources from which you can obtain materials about scientific careers? Have you explored the wealth of materials flooding your Guidance Department? Do you work closely with your guidance officers to screen and utilize these materials?

9-4. You may find it useful to start a card file listing governmental, collegiate, and industrial scientists who would help you and your students. One small school has a list of over 60 within their own town. If you are now teaching, would your PTA or the children help search out your local resource people and gain their cooperation? Would this stimulate greater public interest in your science program and in the school?

9-5. Have you examined closely the publications, books and periodicals, available in local school and town libraries? If you are now teaching, have you explored the possibilities that the PTA, local service clubs, or even the school system itself might finance many of the items you need for the use of the boys and girls? Are there scientists near you who would give the school their copies of journals useful with students?

9-6. What steps would you take if you were to explore the possibilities of developing special opportunities like those described here? What persons and groups would you contact for advice and encouragement? On what problems of scheduling, pupil motivation, facility usage, equipment, and so on, would community support be helpful? On what aspects of the proposed activity would community support be critical?

9-7. The bibliography following is intended to help you develop your own inventions in teaching the science prone. (Note the recency of the publication dates. Is this but a present trend soon to give way to another interest?)

American Association for Gifted Children, *The Gifted Child*, ed. by Paul A. Witty, Boston: Heath, 1951.

Baker, H. J., *Introduction to Exceptional Children*, N. Y.: Macmillan, 1953, pp. 282-89; rev. 1955.

Barbe, Walter B., "Differentiated Guidance for the Gifted," *Education*, 74:306-11, Jan. 1954.

Bennett, P. L., "Reading and Writing Programs for the Talented Student," *English Journal*, 44:335-39, Sept. 1955.

Brandwein, Paul F., *The Gifted Student as Future Scientist*, N. Y.: Harcourt, Brace, 1955.

——, "The Selection and Training of Future Scientists," *Scientific Monthly*, 54:247-52, 1947.

——, "The Selection and Training of Future Scientists, II. Origin of Science Interests," *Science Education*, 35:251-53, 1951.

The teacher's responsibility

Each science teacher must answer this question for himself: "What is my part in the stimulation of students with high ability in science?" A plan found useful in one large high school has been sketched here. No doubt better plans are being practiced and it would be exceedingly valuable if these were thoroughly described.

One thing is clear. In school every year are certain students who may become competent scientists. Whether they will or not depends in part on us. These students should be given an opportunity to develop their skills at the earliest possible time. Where varied and attractive opportunities are available, interested students will seek to fulfill themselves in science.

It is urgent that professional science look to its sources: a steady flow of the highest type of young men and women, and the facilities to train them. And, most important, we need—desperately—the teachers who have the training and maturity to develop the future scientists of the United States.

If, indeed, the boys and girls of this country are the national resources upon which we must draw to solve the pressing problem of our shortage of scientists, then those who teach them remain the key to the solution of this problem.

An excursion into developing your own invention in teaching the science prone

9-1. A Problem: What is your opinion on the following pairs of statements?

(a) 1. "In a heterogeneous group, the bright child discourages his classmates; often he misleads his teachers as to the capabilities of his classmates."

2. "In a heterogeneous group, the bright child has the opportunity to lead."

(b) 1. "Heterogeneous grouping is democratic; in a democracy different groups live together cooperatively."

2. "Heterogeneous grouping is undemocratic; in a democracy we are free to choose our own associates and we choose those in our socio-economic and intellectual group."

9-2. Have you seen:

(a) *Encouraging Future Scientists: Keys to Careers* (information on careers, awards to "future scientists")

(b) *Encouraging Future Scientists: Materials and Services Available* (where to go for help).

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Section Three

INVENTIONS IN SCIENCE COURSES

In this section on scope and sequence we shall examine the science curriculum. Our effort is to present various examples of what high school science teachers mean by chemistry or biology or physics. Separate chapters will present the "structure and approach" for each science course in various schools and for various students. In this way we hope to provide not only useful descriptions of the courses, but also insight into the total science curriculum.

By definition, a curriculum consists of all the activities, both intent and content, within the school which fit the purposes or objectives of the school. It consists not only of courses of study, areas of scholarship, but also of activities in class and outside of class (field trips, assembly programs, special projects, etc.). Yet when teachers speak of revising the curriculum, they speak mainly of the individual courses of study. Rarely do they mean all the activities which serve the school's purposes.

This entire section of nine chapters is, in a sense, a single chapter. It is concerned with the total science curriculum, with all the courses of study and all the activities. Chapter 10 sets out some general comments, questions, and viewpoints. The following six chapters develop each subject area. Chapter 17 deals with the unit within the course, and Chapter 18 is the continuation and conclusion (the "Excursion," as it were) of Chapter 10.

At the end of this study in scope and sequence, the science teacher should have a starting point and direction for his efforts to develop or modify his own curriculum and courses. This can be done despite the diversity of schools and students because the major questions that must be asked are the same everywhere. Only the answers are tailored to local conditions.

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widely accepted by educators. In 1900 this was not so, nor was it so in 1920. This is clearly a recent trend. An example of such a continuous curriculum plan, in New York City, is presented in Table 10-3. Similar plans may be obtained from most of the agencies concerned with curriculum development in the major cities of the country.

Whether or not we approve of the particular plan diagramed is not the point. It is an example of a major development in science education throughout the country, the creation of a continuous science program from the kindergarten through the twelfth grade. What effect will such a program in science have on the thinking of people in the next two or three generations? On their skills? Knowledge? Attitudes?

Continuity of experience in science means more than just a sequence of subjects; it also means a sequence of larger concepts or problems in many areas within a curricular organization that serves the purposes of the school. Note (Table 10-2) how the Forestry Service of the U. S. Department of Agriculture, in collaboration with teachers who specialize in this area, conceived of the introduction of problems and concepts dealing with conservation. Note, also, how their development of the problems and concepts of conservation is related throughout the grades. Only a condensed version is given here; the complete statement may be obtained from the Forestry Service.

Concern for and the design of a twelve-year science program does not imply that all students will be enrolled in the program every year. Table 10-1 indicates the percentage of pupils in the last four years of public secondary schools who have been enrolled in high school science courses.

While the figures in Table 10-1 are as accurate as we could wish, *they present a misleading picture, for two main reasons:*

First, the percentage of young people of the appropriate age who do enroll in high school has increased tremendously over this span. Between 1900

TABLE 10-1 Percentage of pupils enrolled in public high schools who were enrolled in science courses *

Year	*General Science*	*Biology*	*Chemistry*	*Physics*
1890 †	—	—	10.1	22.8
1900	—	—	7.7	19.0
1910	—	1.1	6.9	14.6
1915	—	6.9	7.4	14.2
1922	18.3	8.8	7.4	8.9
1928	17.5	13.6	7.1	6.8
1931	17.8	14.6	7.6	6.3
1949	20.8	18.4	7.6	5.4
1956	21.8	20.5	7.5	4.4

* Kenneth E. Brown, *Offerings and Enrollments in Science and Mathematics in Public High Schools*, U. S. Department of Education Pamphlet No. 120, U. S. Government Printing Office, Washington, D. C., 1957.

† *Biennial Survey of Education in the United States 1948-50*, U. S. Government Printing Office, Washington, D. C., 1951, Chapter 5, p. 107.

CHAPTER 10

Inventions in science courses:

Introduction to course building

A note at the beginning: This is an introductory chapter to be extended after a study of this entire section. The reason for this is plain We cannot profitably consider the development of a complete science program until we have examined the thinking of teachers, those who put courses of study into practice by using them to help children learn, and in learning, grow

In Section I we examined some aspects of the scientific enterprise: what scientists do and why, and what this means to teachers of science. In Section II we considered patterns of science classes and of science teachers. Always, as we have emphasized, planning is the key to effective teaching. Now we turn to the basis for over-all planning of science teaching—the science curriculum. What is being done throughout the country? How is this different from what was formerly being done? How has the curriculum failed to change even though many have stressed the need for major changes? In the curriculum we bring together the several threads: science, learning, children of different attributes, and teaching.

Trends in development of the science curriculum

While no one can speak authoritatively for curriculum development throughout the United States, several general lines, or trends, in the development of the science curriculum seem evident during the past fifty years.

Trend 1. *Continuity in science experience*

There is clearly a tendency to develop a curriculum from the elementary school through the high school. A continuous science experience is being

SENIOR HIGH SCHOOL

Understanding, Controlling, and Improving Group Relationships, and Trends in Modern Society

Improvement of living conditions through adaptation of forest products for construction, insulation, and beautification. The relation of forests to housing; prefabrication of wooden houses.	*Making a home*
Stabilization of employment in forest work and forest industries by proper management (conservation) of the forests. Changes in forest labor conditions. Best use of land. Greater utilization of forest products, not substitution, means greater possibilities for conservation. The problem of the people on submarginal lands best fitted for forest production.	*Earning a living*
Developing and utilizing our forest and range resources for the greatest good to the greatest number. Cooperation between federal government, states, and private forest landowners in forest protection, tree planting, forest management and forestry extension. Wise use of the natural resources for national security and prosperity. Forests in our national defense program.	*Performing the responsibilities of citizenship*
The place of research and planning in regard to conservation of natural resources. Reforesting devastated forest areas and submarginal farm lands. Prevention of wasteful exploitation. The interdependence of natural resources, importance of forests in conservation of soil, water, and wildlife. Scientific use of forest resources in harmony with the balance of nature. Protection and use of watersheds. Irrigation, hydroelectric power, and navigability of streams maintained by forested and well-grassed watersheds. Forest highways, purposes and values. Forest and range conservation as a land use policy. Tempering winds and cold by establishing shelter belts, relieving strain of monotonous landscape.	*Conserving and improving material conditions*
The maintenance of national and state forests as scenic areas.	*Expressing spiritual, aesthetic, and emotional impulses*
The maintenance of primeval areas in forests without human use or interference, except to protect from fire, to enjoy, and to traverse only by foot or horseback or canoe. Forests as living memorials. Why the state and federal governments provide forest recreation. Recreation and employment. How management of forests is adapted to recreational needs. Recreation as a land use. Recreation to achieve more balanced living.	*Engaging in recreation*

TABLE 10-2 *Integrating forestry in the modern curriculum* *

	Elementary school *Influence upon Life in the Home, School, and Community*	Junior high school *Adaptation of the Individual to his Physical and Social Environment*
Making a home	Things in the home from the forest. Home life in forest lands. Effect of abundance or scarcity of forests upon houses. Improving home ground through tree planting and care	Importance of forests to housing in this and other countries. Comparison of uses of forest products in colonial and modern homes. The varied uses of different woods.
Earning a living	How the pilgrims, Indians and pioneers used the forest and western range lands. What the woodsman does. How forest industries give work to many men, rural and urban. What the farmer uses and sells from his woodlot.	Making more efficient use of forest products, elimination of waste. How different parts of our country and other countries use their forests. How forests affect transportation, communication, trade, industry, and agriculture. How forests determine where certain industries develop. The importance and uses of the standing forest.
Performing the responsibilities of citizenship	Our manners in the woods. Preventing forest fires. Protecting our forests from insects and diseases. How the forest ranger protects the forest. How planting new forests helps the community.	Some great leaders who have helped establish forest conservation policies. The agencies of government that manage our forests and range lands. How forests aid in the development of other natural resources. The duty of the citizen toward forest conservation.
Conserving and improving material conditions	Caring for and protecting plants and wildlife about the home and in the community. Improving home environment with trees. Forest homes and communities endangered by forest fires. Tree planting stops erosion	How forest fires start and are controlled. Destructive practices in the use of forests and ranges. Technical advances in lumbering. Research in forest use and its application to industry and community stability. What may be done to improve forest and range use. How reforestation and other forest improvement work is carried out. Importance of soil to plant growth and to clean waters.
Expressing spiritual, aesthetic, and emotional impulses	Use of trees and shrubs in beautifying home and school grounds. Telling others how forests serve us. The lessons we learn from the forests.	Architectural uses of wood. Methods of finishing wood to bring out its beauty. Preserving and creating beauty in the forest environment. Inspiration from and enjoyment of the natural beauty of forests.
Engaging in recreation	Kinds of forest recreation appealing to children.	Making forest recreation areas available to more people in all parts of the country. Establishing community forests. The development of the sylvan forests. Healthfulness and adventure of forest recreation. Advantages of forest camps for young people.

* Adapted from *Suggestions for Integrating Forestry in the Modern Curriculum*, Forestry Service, U. S. Department of Agriculture, rev. August 1932. Also ask for publication K 28, *Materials to Help Teach Forest Conservation*, Forestry Service, U. S. Department of Agriculture, 1932.

Senior high school			
Academic			*Vocational*
Regents	*General*	*Special and advanced*	
Biology †	General biology	Biological techniques	Basic science
Earth science †	General earth science	Qualitative analysis	Related science
Chemistry ‡	Applied chemistry	Advanced chemistry	Vocational—trade
Physics ‡	Applied physics	Advanced physics	Vocational—technical

† Offered in tenth grade
‡ Offered in eleventh and twelfth grades

d. The enrollment in elementary algebra (1,204,500) is equal to 64.5 per cent of the number of pupils in the ninth grade.

e. The enrollment in geometry (664,100) is equal to 37.4 per cent of the number of pupils in the tenth grade.

The data above are based on a study of a 10 per cent sample of public secondary day schools.

Nation-wide over 1,300,000 pupils, approximately 72 per cent of all ninth graders, are enrolled in general science. Is this course, often a required one, meeting the needs of the children? For many children general science, with perhaps biology, are the final courses in science. Are these courses helping them become adequately prepared to meet their personal, community, and national problems involving science?

Why are 72.6 per cent of all tenth-grade students enrolled in biology? Why is the enrollment in chemistry only 31.9 per cent? And that in physics only 23.5 per cent? Is it because biology meets the needs of more young people? Is it required? Is it easier? Is it better taught? Or are there other reasons?

Questions such as these will be considered in the following chapters.

To the reader: You may wish to turn now to *p. 217, near the end of this chapter,* *where we describe briefly a* continuous curriculum, *from elementary through high school, with special emphasis on different programs for students of different abilities and (apparent) destinations.*

Trend 2. *Diversification*

Even a cursory examination of the curriculum plan in Table 10-1 shows that attempts are being made to meet the needs and interests of various kinds of young people. Clearly the differences in age level are being considered.

TABLE 10-3 Science in elementary and secondary schools *

ELEMENTARY SCHOOL	JUNIOR HIGH SCHOOL
Plants and animals: how they live, how they help man, how they help each other	*Grade 7 You and your place in the world:* getting acquainted with yourself, getting acquainted with your world.
Weather: its manifestations, its effects on man, how man protects himself from it	*Grade 8 How science helps you meet your basic needs:* increasing and improving your food supply, improving your housing and clothing; making work easier.
Communication: by sound, by telegraph, by light, by radio, by television	*Grade 9 A better world through science:* our atomic world; prolonging your life; improving communication; speedier transportation, new worlds to conquer.
Transportation: on land, on water, in the air	
Electricity: how it works for us, how it is distributed	
The earth and its materials: its resources, its changing surface	
The earth in space: the objects in the sky, the solar system, the universe	

* From *Curriculums and Materials*, Vol. 10, No. 1, Board of Education, New York City, Sept. 1955.

and 1950 alone, this percentage increased from 8% to 64%! Thus even where the percentage of high school students enrolled in a particular course has decreased, the percentage of the *total high-school-age population* taking that same course has obviously increased considerably. In short, more of our young people are taking science courses than ever before.

The second reason is indicated clearly by Brown: [1]

> Instead of using all the pupils in the last four years of high school as a base for computation, perhaps it would be easier to understand if the base were the number of pupils in the grade in which the subject is usually taken. For example, the number of pupils enrolled in physics in the fall of 1954 was 4.6 per cent of all the pupils in high school. Also it was equal to 23.5 per cent of the number of pupils in the twelfth grade. It is true that all the pupils enrolled in physics were not from the twelfth grade. Some were from the eleventh grade. Also some of the twelfth grade pupils in 1954 took physics the previous year. However, it is reasonable to assume that 23.5 per cent is approximately the percentage of high school graduates in 1954 who have had physics.
>
> Using the grade level enrollment at which the subject is usually taken as the base, the percentages of pupils enrolled in certain science courses in the fall of 1954 are given below.
>
> a. The enrollment in biology (1,293,900) is equal to 72.6 per cent of the number of pupils in the tenth grade.
>
> b. The enrollment in chemistry (182,700) is equal to 31.9 per cent of the number of pupils in the eleventh grade.
>
> c. The enrollment in physics (302,800) is equal to 23.5 per cent of the number of pupils in the twelfth grade.
>
> Similar data on enrollments in high school mathematics in the fall of 1954 are:

[1] Kenneth E. Brown, "National Enrollment in High School Science," *The Science Teacher*, March 1956.

science is used to differentiate it does indeed look to the development of *experts*. Hence there is a trend toward developing science programs for all, within the framework known as general education—for the expert in science and the non-expert.

Trend 5. *Correlation of subject areas*

Even when science was taught within a narrow boundary, scientific information and experience necessarily spilled over into other areas. After all, it is one world, no matter how we choose our viewpoint. For instance, conservation and the history of science are discussed in social studies courses, atomic energy in economics, water supply in civics, problems of volume and flotation in mathematics.

Similarly, other areas necessarily spill over into science. Certainly graphs and equations as well as arithmetic are continually involved in science. Language arts are critical in science, for scientists think and communicate clearly and students must also. Social studies enter whenever any scientific topic is followed into the social world of technology, economics, and social judgments as a basis for action.

Where a problem of wide implications is introduced, it is very often handled in many areas at once. Note, for instance, the example of the treatment of floods shown in Table 10-5.

Of course, modern elementary schools, which are not departmentalized, and some high schools have been correlating their science experiences in "core programs" (see Chapter 11, Science in the Elementary School). Science in the core program will be discussed further in Chapter 17.

Trend 6. *Increase in laboratory work*

Early in the development of science teaching in this country, not only was laboratory work consistently a part of the planning of high school teachers, but it was inconceivable that a high school could be built without a laboratory. Also, the double laboratory period was a frequent practice.

Now we seem to note these trends. First, laboratory work, that is, work done by students as compared with demonstration work by the teacher, is an integral part of science teaching. In fact, laboratories are now built in junior high schools, and laboratory corners are beginning to be found in the elementary schools.

However, up to the time of the earth satellite the amount of *time* given over to laboratory work as compared with demonstration work seemed to be decreasing. We noted, for instance, fewer and fewer double lab periods, and more and more demonstration work suggested in published curriculums. We noted a tendency to build *fewer* laboratories in the new schools, although some laboratories are included in all schools. The satellite highlighted our needs in science and this trend of decreasing lab time seems to be on the reverse.

Note the type of material proposed for the elementary grades and compare it with that for the junior high and senior high school grades.

Differences in aptitude are also being considered. Applied chemistry is less difficult than the Regents or college-preparatory chemistry course; for it involves less mathematics, less detailed knowledge, and less use of formulas and equations.

Trend 3. *A change in the purposes of instruction*

There was a time when courses in high school were given over to "preparedness for college." In some schools this objective still exists, but not in its utter purity, it is being modified and the science taught in these courses is being made significant and operational in the lives of young people as they develop toward adulthood. The memorization of information is not the sole purpose of instruction, concept forming through problem solving is gaining increasing importance.

The distinction perhaps is made clearer by an example from the course of study in *Science for Secondary Schools* published by the State of Pennsylvania (Table 10.4). The committee which developed the bulletin purposely chose a topic which is standard, prosaic, and information-centered, to show how even a topic of this type might be given meaning. The content of this example is not especially important; the intent is. A study of the chart at the end will indicate the reasons behind the unit outline. The chart indicates *one* reason for teaching science. Science can be used to meet the imperative needs of youth.

Trend 4. *Individualization of instruction*

There is an attempt within any class activity to involve as many individuals as possible, to allow all interests to display themselves. Note the sample teaching plan in Table 10-4. Extracurricular activities are within the purview of this trend; so are special classes; so are projects and reports. The gifted, the able, the middle-of-the-road, the less able are also in the picture.

Clearly it is evident that science in the public secondary school is emerging as a part of general education (see Trend 9). This does not mean that science is not being used to attract individuals who will later make it their life work (see Chapter 9, The Science Prone). Indeed, we should *never* infer that a content area in general education is not meant to appeal to those who will specialize; the word "general" should not, and is not meant to, have the connotation of exclusion.

General education is meant to connote education *for all*. It looks first to the education of the individual as a human being living in our present and future society. Hence general education is meant to *integrate* as well as *differentiate*. Where science is used to integrate, it is meant for all young people; for they will need to solve those problems in which science plays a part, and they will need to co-operate with experts (doctors, engineers, scientists, etc.). Where

	The old	The new
Activities	Put week's assignment on board. Make large diagram of fish on board. Present the topic and label the diagram. Show some pictures of fish. Read and discuss texts with class daily as preparation for home assignments. Conduct class recitations on home assignments.	Group planning for individual and committee activities and reports to accomplish following: Provide for research as many books on fish as can be obtained. Secure and display around room colored pictures of fish (motivation). Secure large biological model of fish Arrange for demonstration dissection of either raw or cooked fish. Contact Home Economics Department and arrange for fish luncheon (teach etiquette). Investigate possibility of trip to an aquarium or hatchery (teach techniques of planning; teach proper conduct in public vehicles). Secure paper, paints, crayons, and arrange for art teacher as consultant for art work Investigate possibility of Saturday hike where fishing can be done (good human relations, leisure time activities, planning, responsibility). Arrange with local sports store for demonstration of fishing tackle, bait, flies, etc. (teach good sportsmanship, leisure-time activities). Consider possibility of having someone teach interested group to make artificial flies (letter of invitation and thanks) Get clay, soap, tools for carving and modeling (permit some of this while research reading is being done). Suggest and assist pupils to secure, furnish, care for an aquarium (teach principles of balance in life; good activity for nonreaders). Find a tropical fish enthusiast and arrange for talk on and display of them (teach reproduction). Stimulate interest of brighter pupils in making scientific investigation, developing booklets, developing reference lists, hunting up classification, accumulating clipping files, sending for free and inexpensive materials. Don't forget keeping of records of all kinds by everyone.
Culminating activities	None.	Committee reports, displays, and individual records.
Evaluation	Give, mark, return tests. Reteach facts not known. Give another test to those who failed.	Arrange for tests of facts learned. Have group discussion of strengths and weaknesses of planning committee work, committee leaders, behavior on trips, learning experiences, development of interests, skills, abilities. What drill and formal instruction are needed?

Whether this is clearly a trend will need to be established in future observations. We would be optimistic, however, to assert that there are major constructive trends in the use of laboratory work in science courses. As we shall see later, the significance of laboratory work has varied greatly within the past fifty years. The present status of laboratory work appears to be far from what it could be, and (on the basis of our description of science as concept seeking) what it *should* be.

Laboratory space and equipment is very expensive, costing about twice as much as the same space fitted as a regular classroom. Scheduling laboratory time, especially the double period, is an administrative headache. For many students laboratory courses seem to have "extra work," both within school time and in the preparation of reports at home. Yet direct firsthand contact with selected phenomena is the essence of science. Often, unfortunately, these selected phenomena are not the result of an orientation toward science as a dynamic intellectual enterprise, nor toward science as relevant to the lives of the children we have in school. An examination of workbooks supports this conclusion.

However, many inquiries confirm our common observation that children *enjoy* laboratory work, even in the routine form followed by most schools. The outstanding success of science fairs, involving extra work on the student's own time, clearly shows that pupils want to work in the laboratory. They want to *do* something, especially when it has meaning for them. The place of the laboratory in our science programs is established, yet the special place the laboratory should play in instruction deserves careful appraisal.

Trend 7. *Increase in the use of mathematics*

Those teachers who have done any kind of research in science know that very few aspects of scientific research can be done without reliance on mathematics. Mathematics is a language of science, aside from being a "pure" science in itself. Yet they know how difficult it is to introduce quantification into science teaching; the use of numbers and mathematics presents difficulty to many students.

There is, however, a noticeable trend to introduce mathematics to quantify phenomena—if only for the science prone. For example, terms such as "light-year" and "half-life" are beginning to appear in general science even though for the non-sophisticated in mathematics these concepts are difficult. Even the calculus is increasingly found in advanced physics courses.

What is the effective place of mathematics in secondary school science? Over the past half-century there has perhaps been a trend to lessen somewhat the mathematical aspects of science courses. This has occurred mainly because certain groups of students were found to be unable to utilize geometric and, especially, symbolic algebraic descriptions. In some instances, probably too much mathematics has been removed from courses for the more capable students. Or, where science shy and science prone are taught together, the science

TABLE 10-5 Relating the flood problem to the curriculum *

This chart shows how a study of the flood problem can enrich all subject matter areas in both elementary and high schools. In addition, such a study provides young people an opportunity to participate in the search for solutions to one of Connecticut's most acute problems.

LANGUAGE ARTS *English,* *Reading,* *Spelling,* *Writing*	Oral and written English in stories on flood experiences; evaluations of field trips and reports on special topics. Letters asking for information and inviting and thanking guest speakers. Reading of newspaper accounts of the flood and doing research on local history. Use in research of a variety of references.
SOCIAL STUDIES *Geography,* *Economics,* *History*	Study of topography, rivers, valleys, mountains, lakes, soils, etc. Map work in relation to paths of hurricanes and place of origin, study of wind movements. Map of Canton and of Connecticut to show flood damaged areas and river systems. Studying history of Canton to determine reason for building on river; inviting a speaker on Canton's early history. Discussion of need to relocate business and homes because of flood. Study of impact of flood on the town's economy; visits to, and speakers from, local industries.
SCIENCE AND HEALTH *Biology,* *Botony,* *Geology,* *Meteorology*	Study of water pollution and effects on health. Study problem of restoring plant life in brooks before fish can be replaced. Study of forestation as a means of checking flood danger. Study of rocks, soils, erosion, water and their relation to floods. Study of danger to health during a flood, need for health rules, inoculations, etc.
ARITHMETIC	Reading, writing, and working with large numbers found in newspaper articles dealing with flood damage. Figuring amount of rainfall per capita which fell during the flood. Computing number of tons of water, also gallons and quarts, which fell in four counties during the flood. Measuring for accurate ruling of charts and bulletin board arrangements.
CITIZENSHIP	Learning to solve problems related to study of the flood through democratic procedures; learning to accept responsibility. Learning the duties of citizens during times of disaster. Learning about agencies which give disaster relief, town, state, and federal. Studying duties of various departments in town government. Discussing how our town can be rebuilt into a better place to live; realizing the importance of town planning in rebuilding for a better future.
ART	Drawing charts to show causes and effects of the flood, agencies involved in relief. Arranging picture displays of flooded areas. Sketching pictures of flood scenes. Making maps of Canton and Connecticut. Arranging bulletin boards. Making of scrapbook of the flood.

* Outline prepared for use in Canton (Conn.) Schools by Mrs. Dorothy Cowles. Consultant Dr. Philmore B. Wass, Connecticut Council for the Advancement of Economic Education. Personal communication from Dr. Wass. Excerpts only are given here.

As we have indicated, considering *all* individuals necessarily includes the future specialist in science or in anything else.

For convenience, man's accumulated concepts and skills are usually grouped in major areas related to the types of problems he encounters in his social, personal, and physical environment. For this reason, general education is often approached through three major avenues: the social studies, the humanities, and the sciences. Although this is a convenient separation, it is an artificial one; for in each of us the three areas are in continual interplay.

Robinson Crusoe may serve as an example. Initially he faced the task of maintaining himself in a new physical environment. Somehow he did not consider seriously the possibilities of suicide. Aside from the "drive" of any living thing to maintain its own life, this decision was based on a code of behavior or ethics grounded in the humanities, the internal basis for his reaction to the world. He was able to delight in a spectacular sunset and enjoy the brightly colored birds even though they did not fill his belly or keep him from harm. Initially his reaction to his environment was based on strong humanistic ideals. Yet he also had to survive and there his science allowed him to use the environment for his own purposes. When Friday appeared, the social studies, the interaction of man with man, entered the story.

As we look at these three major areas, we ask what they can provide, individually or collectively, toward meeting the general objectives. How can science, mathematics, the social studies, the language arts, music, and art serve the objectives of general education?

After this is answered, at least temporarily, we ask, what can I, the teacher, contribute through this course to the general development of these students? The answer, within the larger framework, gives purpose and direction to the specific activities of the class.

A course or curriculum designed on this basis is part of an over-all program of great significance and continuity. As we shall see, this larger approach, necessarily student-centered, is oriented toward the development of adults better able to meet the complex and unforeseeable problems of the future.

Conflict with the "classical" organization of each subject is inevitable. Especially is this the case with instruction in science, for each of the sciences has a formal, academic structure which has commonly been the basis of instruction. Yet the colleges themselves have been very active in restructuring their course programs to provide general education. Perhaps then the classical structure is not the only one possible.

In the science classrooms of secondary schools reorientation of instruction has come slowly despite the counsel of educational leaders for several decades and the reformulation of courses within a few schools.[2] For clearer evidence

[2] A major effort to interpret general education in science within the secondary school was the volume by the Progressive Education Association, *Science in General Education*, D. Appleton-Century, N. Y., 1938. This was published just as World War II was breaking out and a strong "practical" orientation appeared in the schools. Apparently the approach recommended and described was too "radical" for science teachers under these circumstances.

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tional upper-division study must be in new "general education" courses or in certain regular courses designated as fulfilling the requirement for a second year of generalized study in each area.

Such a pattern does not add to the normal number of courses taken for "distribution," but substitutes broader courses for those previously available. This is one indication of the ways in which the colleges have recognized their responsibilities for common, or general, education as well as for specialization.

When the colleges became deeply concerned about their educational programs for *all* their students, many of them reacted quickly. Much the same line of argument for basically altered instruction in the secondary school has been available for years, but little has happened. In the following chapters we shall examine the factors which have delayed this reorientation in science in secondary school classes.

Apparently, general courses are considered important in college. Yet those institutions enroll only about one-sixth of the age group. A much larger fraction of all the future adults go to high school. Therefore, if general courses are valuable in college, would not similar courses, with appropriate changes in instructional material, be even more desirable in high school? A close look at the basic ideas underlying the science curriculum in secondary school may suggest that the courses offered there—biology, physics, chemistry—are unwisely phased in the educational pattern.

A continuous, multi-track curriculum

We hear often of the superiority of the European or the Russian plan for producing scholars, scientists, and engineers. Yet in many of our school systems students with many and varied gifts are given opportunities to learn, do, and become as much as they can. That these opportunities are not forced on our students is an inevitable concomitant of a democratic philosophy. But just as inevitable is our obligation to provide them, and even make them as attractive as possible.

Where special provisions are not already available for those students who can run fastest intellectually, they must be devised. Perhaps the pattern presented here (already in practice in one modification or another in a number of school systems) will be useful as an example. It is one way of making provision for all types of students, with all types of destinations.

The following descriptions of the tracks refer to the diagram on page 218.

Track 1. All boys and girls who are educable (meaning boys and girls with sufficient capacity to remain responsible in their social acts) go through high school. Track 1a indicates provision for the lowest I.Q. ranges (special programs to fit these students for civic responsibility).

This general program would include all areas now taught in our schools—English, social studies, science, mathematics, language, physical education, art,

of what general education in the sciences means in practice, we must turn to the collegiate experience

In the 1930's at the University of Chicago, Colgate University, and the University of Minnesota, serious attention was given to the existing pattern of collegiate instruction This had consisted of a "major" field of study plus some other courses, often six, in other fields required for "distribution." But the courses available for "distribution" in the sciences were the introductory courses for those who might become "majors." Especially within the highly structured sciences, this made little sense. Of what value was Biology 1 or Chemistry 1 or Physics 1—each admittedly an introduction to further work—to a future poet, a future legislator, a future housewife, a future industrial or labor leader? Each course was filled with technical details for the future specialist, while the large ideas which give meaning and significance to science were given little emphasis. One learned much about the results of science, but little about how these were attained or established.

Thoughtful searching by the college faculties focused within each of the three general areas (social studies, humanities, and science) on certain general or grand concepts, which would allow the future nonspecialist to appreciate and comprehend what the specialists were doing. An additional advantage of this plan was that it ensured that every student would consider major topics and problems in various fields; previously many graduates of the same institution had shared no experiences with their classmates.

After World War II ended in 1945 many colleges re-examined their programs of instruction and introduced "general courses," with completely new content and new instructional procedures. In the sciences at first the "survey" course seemed to be an answer. But this was soon recognized as a "once over lightly" approach in which the major concepts were lost among even more details than the "major" course offered.

Intensive study of selected materials offered a better opportunity to get out the ideas without overwhelming the student with details. Such courses have been termed "block and gap" courses; they are basically what had long been in the educational literature as "major units" having a unified idea or theme. Case histories were used as one of several means of organizing blocks of study and focusing upon the active part of science rather than only upon the results of this activity.

During the initiative and intensely creative phase of this reorganization, about 1945 to 1952, a new journal, *The Journal of General Education*, was founded. Also a considerable number of books spelling out various points of view and describing college courses were published. A list of these analyses is given at the end of the chapter, in case you wish to read further in this subject.

Generally each student is expected to take at least one full-year course in each of the three major areas: humanities, social studies, and science. In some colleges the required sequence extends for two years In other schools, addi-

involving all areas—astronomy, biology, chemistry, physics, geology, meteorology—through selected concepts appropriate to the junior high school boy and girl. The importance of not giving the special sciences here is that 12, 13, and 14 year olds should be given an opportunity to look into all branches of science, each and every year, to determine their interest and ability. Mathematics should be used throughout these sciences.

The *best* teachers belong in these years; for generally students tend to bend clearly, in the junior high school years, toward a specific career selection.

In the ninth through the tenth grades in this track, a definite selection begins, in which both students and teachers have a hand. First, in the junior high school years, students have begun to find out whether science is for them. Second, because in the future we may place very good teachers in the junior high schools, excellent teaching has made science extremely interesting, exciting, and enticing. Third, testing (by standard tests) has helped to identify those with ability and special interest.

In the large high schools, we now can homogeneously group students who have similar interests and destinations (i.e., science-bound, art-bound). In the small high school, small classes, even of three or five, may be necessary.

All students in the college-bound group (Tracks 2 and 3) may take (for five class hours per week) 4 years of English, 4 years of social studies, 4 years of science, 4 years of mathematics, and 4 years of a foreign language, based on the work begun in elementary and junior high school. In addition, all students take 4 years of physical education and 4 years of a combined music and art curriculum (i.e., two or three periods per week each of art and music).

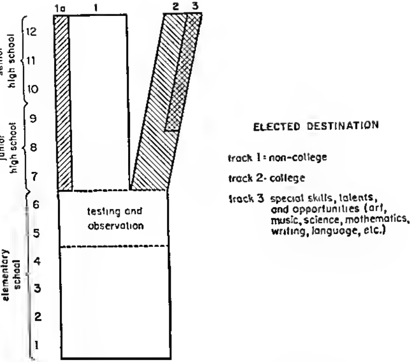
However, for those who have already shown a decided preference in music, art, science, mathematics, history, or another subject, a third track is made available.

Track 3. In this track, students work at being scientists, artists, musicians, mathematicians, or writers. They take a project (perhaps cosponsored by a university) in some phase of science, mathematics, the arts, or humanities. In science and mathematics, this is actual research on a small problem (see Chaps. 3 and 9).

This kind of program is already being accomplished in most schools for athletics, art, and music. It now needs to be done for other areas.

A study of the science curriculum

In view of these several trends would it be sound to begin a study of the science curriculum with a statement of the principles underlying curriculum building in science? This is precisely what we do *not* intend to do. First we shall analyze various science courses: science in the elementary school, biology, chemistry, physics, and last, because they are derived from the other courses, general science and physical science. Then we shall be concerned with the development of the "unit" within the course. Finally, at the end of the section,



music, and so on. Science would be generally nonmathematical in nature, although it would require the simplest algebra and geometry (i.e., mathematics of proportions) for the solutions of problems

Track 2. This track is for boys and girls who show the intellectual qualities necessary for success in college. It involves roughly 30 to 40 per cent of our student body.

In the fifth grade and sixth grade, observations and testing are to be done to determine the special gifts of these boys and girls. At the same time, special opportunities (e.g., enrichment in language, literature, science, arithmetic, history, art, and music) are to be made available to them. In the fifth and sixth grades, these young people are not to be segregated into homogeneous groups.

In the seventh, eighth, and ninth grades, they are to be homogeneously grouped. Naturally, since the students have different career destinations (some in science, some in social studies, some in literature), this grouping is homogeneous only for college destination based on student ability and parental consent.

In the seventh and eighth grades, an enriched program in general science and mathematics might be offered. The science would be a general science

we shall in a sense complete this first chapter in a chapter-length "Excursion" into building and revising the science curriculum.

A bibliographical excursion into science in general education

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CHAPTER 11

Inventions in science courses:

Science in the elementary school

A note at the beginning: Every student in high school science classes attended elementary school. The science experiences which these students had in elementary school varied from school to school and from student to student. Yet, generally speaking, whatever experiences each had will affect his approach to the study of science in high school. The student entering high school is even less a "clean slate" than when he entered elementary school.

In recent years children have had more and richer experiences in science in the elementary school. In planning what science to teach in the high school, we must recognize that many children have already studied and learned well certain things that previously were taught for the first time in general science or even in biology, chemistry, and physics classes.

What science do children study in the elementary schools today? This chapter will summarize a few of the important trends and characteristics of science teaching in the elementary school, as well as some of the characteristics of children as they learn science.

A series of visits to elementary school classrooms by high school science teachers is an excellent way to become familiar with the amount and kind of science teaching in the elementary school. Ideally, visits should be made in the primary, intermediate, and upper grades, preferably in the state or school system where the high school science teacher teaches or plans to teach.

To supplement his classroom visits, the high school science teacher should examine sample science guides, science textbooks, and courses of study in common use in the elementary schools. He should also talk with children, teachers, principals, and supervisors to get their interpretations of what and how science is being taught.

Emphasis on science in the elementary school

Such inquiries into the kind and amount of science taught in the elementary school will show a wide range In some classrooms children have little formal experience with science. In others, their science is related to a number of "symbols" such as aquariums, science corners, collections of plant or animal life, or care of pets. In still other classrooms, opportunities for science investigation and inquiry are sporadic. They occur from time to time when unanticipated events lead to questioning and study. Further, in other classes, a definite unit of study or program plan is systematically followed, giving regularity and continuity to the children's science learning This plan may be suggested by a textbook, by a resource guide adopted by the school system, or by a plan developed by the teacher and the children around a series of centers of interest which they have selected for study.

Even though elementary schools generally have a commitment to teach science, individual schools and classes vary in the amount of time they devote to science. In some classrooms science is taught for 15 to 30 minutes every day, in others for 30 to 45 minutes twice a week. Often the methods used by teachers determine the amount of time spent in science. In the typical classroom which operates largely under the guidance of one teacher, children may have opportunities to work individually or in small groups on science investigations. There the time "devoted to science" cannot be measured strictly in terms of the amount of time the entire class engages in a common science activity.

Regardless of the current status of science teaching in any elementary school, almost without exception all persons concerned with improving the elementary school program—principals, supervisors, teachers, students—are looking for ways of ensuring that children have a rich experience in science.

In keeping with this emphasis, nearly every state department of education has issued one or more bulletins on the teaching of elementary science. Many counties and cities have likewise developed suggested courses of study in elementary science.[1]

Purposes of the science program in the elementary school

Those who plan the educational experiences of children intend that school should prepare children in certain skills and knowledge required for successful living. Among these skills are learning to read, write, handle numbers, and speak correctly. In addition children learn to plan, to think critically, to evaluate their progress. As group members they have certain common interests and needs, and require experience in working together toward common ends.

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[1] *Science Courses of Study*. National Science Teachers Association, 1201 16th Street, N.W., Washington 6, D C, 16 pp., 1955

Children learn these skills as they gain in knowledge in many areas: geography of their home, community, state, nation, and world; history of their city, state, nation, and world; care of the body and maintenance of health; and appreciation of literature, art, and music. And certainly not least of all, they acquire intellectual skills as they study the natural world around them, that is, as they study science.

At the same time they need to attain increasing knowledge of the complex world with people of differing opinions and aspirations; a world in which technology differs from country to country from the most primitive to the most advanced; a world made smaller because of advances in communication and transportation; a world more complex because more people are brought oftener into contact.

Thus the elementary schools have a great task. And in good elementary schools teachers, administrators, supervisors, parents, pupils, and others think together about these various responsibilities.

It is within this framework that the reasons for teaching science in the elementary school must be considered.

General education in science

In a sense the purposes for teaching science in the elementary school are the same as those for teaching science in the high school. Yet the way elementary school teachers think about these purposes is tempered by their knowledge of children and how children learn. A statement of the purposes made by a group of elementary teachers is usually quite a simple list. One group stated these purposes this way:

To satisfy the curiosity of children.

To help children answer their questions.

To help children find out how things work in our natural world.

To learn which things should be believed and which are superstitions.

To help children learn how to get accurate information and to think clearly in solving their problems.

To help children with their interests and hobbies.

What more challenging purposes could one seek? Though these may seem unsophisticated, even a casual analysis of the statements reveals that in them is implied the most sophisticated interpretation of why we teach science. (More refined statements of our purposes for teaching elementary science are available in the numerous books on the teaching of science in the elementary school, and throughout state, city, and county guides on elementary science.)

To say, for example, that our purpose is "to satisfy the curiosity of children" or "to help children answer their questions" or "to find out how things in our world work" recognizes that children are investigators, that they seek to form concepts. They ask questions. Among the questions are many that relate to interpreting the natural world. Why is it dark when the sun goes

down? What color are crows' eyes? How does a dry cell work? How does a bee make honey? Children probe into every aspect of their environment in a continuous attempt to describe and understand the relationships between things around them, gaining considerable knowledge and skill.

They use all their senses They touch, they taste, they listen. They smell things, they feel them. In every way known to them children seek to discover for themselves knowledge of the world which, in most instances, has been learned by other children, and by mankind, before them. From birth they have been seeking and forming concepts.

In the elementary school direction and guidance are given to children in their search for knowledge about the world around them. And in this process children are helped to think clearly, to employ various means for acquiring information and, with increasing maturity, to learn how to answer questions and solve problems of importance to them.

To know "which things should be believed and which are superstitions" requires first a knowledge of the interrelationships between forces and events in the natural world. Children in the elementary school are helped to observe the consequences of various common things which are brought into relationship with each other. For example, a pan of water placed over a gas fire will get hot. If the fire is intense enough, the water will boil A pan of water on a fireless burner usually does not boil. Only out of ignorance would someone insist otherwise. These are statements of generalizations derived from repeated observations and retested many times by many people. In the elementary school children observe through many experiences that certain natural phenomena do occur and can be predicted with considerable accurary. It is hoped that, in this way, children will develop the habit of examining many generalizations which can be easily tested, and that they will require similar tests of generalizations which have acquired the label of "superstitions."

Helping children learn how to think clearly, how to answer questions, how to seek concepts as they solve problems, is a purpose in all subject areas of the elementary school. Yet in science teaching there are unique opportunities. The opportunities are implicit in the methods of inquiry which children are encouraged to use in stating their problems clearly, formulating possible answers, utilizing a variety of materials and sources to get relevant information, arriving at answers, and checking their answers in many different ways. Good science teachers in the elementary school realize that children gain skills in thinking, and in acquiring a sense of the processes of scientific inquiry, through opportunities to make real investigations. These are basically the same major objectives of science as in the secondary school. The pattern is consistent.

Preparing future scientists

A purpose of teaching science in the elementary school is to help students gain knowledge that is important to them as children and later as adults.

In this sense science in the elementary school is a part of the general education of all persons.

But teachers are aware that children with science interests may choose scientific vocational pursuits. Among the children in the elementary school are some whose dominating interest in science is evident from the first day of school. In others, interest in science develops later, after they have had formal experience with science. Good teachers know that these interests, whatever their origin, must be nurtured and kept alive throughout the elementary school years. From children with interest in science will come our scientists, engineers, and mathematicians.

Though the vocational aspects of science are usually minor considerations in the elementary school, sensitive teachers are constantly aware that providing children with interesting science experiences will keep open the possibilities of an eventual career choice in science.

Types of science programs in the elementary school

The content of science

The content of science in the elementary schools has a great similarity from state to state and from school to school. This is true, in part, because the source of this content is the natural environment. To children, just as to adults and scientists, this consists of the earth and sky; heat, light, sound, electricity, and other forms of energy; water, air, and rocks; plants, animals, the human body, and other living things; airplanes, rockets, and atoms. It is these things that children study, searching in an introductory way for stable patterns as the basis for predictions.

Although there is a great similarity in the content of science, there is less uniformity as to the way the study is approached, the organization, or the total amount of science in the school program. An examination of several different guides and courses of study will indicate how the content of science is sometimes organized in the elementary school. Four somewhat different types of content organization will serve as examples.

Type 1. The same topics for all grades, but different and increasingly difficult aspects of the topics studied from grade to grade (one-year cycle). An example of this type of organization is found in the North Carolina publication, *Science for the Elementary School,* from which the outline for Grades 1, 2, and 3 is shown in Table 11-1.

Type 2. The same topics for primary, intermediate, and upper grades, with different and more difficult aspects of the topics designated for the higher grades (two- or three-year cycle). An example of this type of suggested science content organization is found in *Science Education for the Elementary Schools of Ohio.*

TABLE 11-1 Content organization, type 1 *

	First year
Animals	Family life Protection and care, food and sanitation Animals eat plants
Plants	Seeds start new plants What plants need in order to live Things that are alive.
Weather	Observing seasonal changes about us. Changing our play Getting ready for weather changes.
Electricity, energy, power, change, force	Making things go by levers Water. Wind
Homes	All animals need a safe home Animal homes. Birds' homes Man's home.

* Excerpts from *Science for the Elementary School*, Publication No 293, State Superintendent of Public Instruction, Raleigh, North Carolina, pp. 30 33.

Six broad areas are proposed in this bulletin:

1. Living things
2. Weather
3. How machines help us
4. The story of the earth
5. Magnets and electricity
6. Health and nutrition

First are stated certain basic understandings involved in the study of each of these areas. Then follow specific understandings that could be developed at each school level—primary, intermediate, and upper. In addition, the bulletin identifies basic questions for study which relate to the understandings.

The organization of one area of study, the weather, is summarized in Table 11-2 to illustrate this type of science content organization

Type 3. Topics for alternate grades the same (two-year cycle). In this arrangement the content topics suggested for grades 1, 3, and 5 are the same, and those for grades 2, 4, and 6 are the same. This organization is a way of

Second year	Third year
Animals change in seasons. Animals differ in food, homes, habits, appearance Animals resemble their parents Water animals in our ponds. Insects in our homes and gardens.	Types of animals that live on land and in water. Some insects in our locality. The life cycle of some insects and animals.
Plants that live in winter, others that do not. Our garden plants—fall, winter, spring, summer. People need plants and animals	Plants in winter. Changes in plants; life span. Seeds and how they are scattered.
Recording the signs of changes in the seasons Preparing for seasons.	Uses of thermometers. Some effects of seasonal changes in plants, animals and man
Making things work by electricity, steam, horses, tractors, air.	Ways electricity helps us work and play. Lightning is electricity. Electricity aids the human eye.
How some animals live in the winter season.	Types of animal homes in water, land, trees, ground. Care and protection of domestic animals.

providing time for sizable units and avoiding repetition of topics to the boredom of children. The topics in this kind of organization may be much like those proposed in the North Carolina outline (Table 11-1), except that certain of the topics would be recommended for given grades and the remaining topics recommended for the alternate grades.

Type 4. Science content based on social studies units. In some schools the science content is based in large measure on the learnings that contribute to the understanding of social studies problems or topics or units. In schools where this approach is made, units that are rich in science possibilities are usually included. And it is usually recommended that units which are for the most part science centered be chosen for study from time to time.

This approach has been recommended in the State of Pennsylvania. *The Elementary Course of Study* suggests that science understandings and attitudes be developed in connection with the study of social living (see Table 11-3).

A teacher familiar with the wealth of possibilities in the study of the environment suggested by the social living topics and questions in Table 11-3 could have a very rich science program in each grade. In order to help all

TABLE 11-2 Content organization, type 2 *

BASIC UNDERSTANDINGS INVOLVED IN THE STUDY OF WEATHER	GRADES 1 AND 2
The sun is the chief source of energy for the earth The earth and its life are greatly affected by the changes in the atmosphere which surrounds the earth Matter may be found in various forms Man has learned to utilize natural forces Man has invented instruments to measure weather conditions and to make it possible to forecast weather	How does the sun help us? What does the wind do? Where does rain come from? How does water get into clouds? What causes water to fall from clouds? When do we see a rainbow? What is snow? What causes ice to form? How do icicles form? How can we make a record of the weather? 1 The sun gives us heat. This heat keeps us warm, melts the snow and ice, and makes our plants grow. 2 Thermometers are used to measure temperature. 3. The wind bends trees, blows paper and dust, carries seeds, and flies kites. The wind blows from different directions. A wind vane points to the direction of the wind. Wind is air that is moving. 4 Rain is water that falls from the clouds 5 Water disappears into the air and forms clouds. 6. A cloud is made up of many floating drops of water 7. Rain falls from the clouds when they are cooled. 8 A rainbow is made by sunlight passing through tiny drops of water in the air. 9 Snow is made up of flakes called crystals No two snow crystals are exactly alike 10 Snow, ice, icicles, and frost are formed when the temperatures are low.

* *Science Education for the Elementary Schools of Ohio*, Curriculum Bulletin No. 5, State Department of Education, Columbus, Ohio, 1916 Excerpts only are given here.

teachers see the numerous possibilities, the Pennsylvania course of study includes a very thorough outline of science understandings that may be related to the various social living units.

There are numerous other variations in the way science content can be organized for teaching in the elementary school. However, the four examples given will serve to illustrate various possibilities If the purposes for teaching science are clear to the teachers in a school, they can undoubtedly be achieved in different ways.

Grades 3 and 4	Grades 5 and 6
Where is air found? What causes winds to blow? How does the thermometer measure temperature? What causes clouds? What causes rain? What causes fogs? What causes snow? What causes sleet and hail? What causes dew and frost? What causes thunder and lightning? How do living things adjust themselves to weather conditions? 1. Air has weight and exerts pressure. 2. Cold air is heavier than warm air. 3. Winds are caused by unequal heating of the atmosphere. 4. Big winds which move across the country cause weather changes. 5. Air contains moisture in the form of water vapor. Warm air can hold more moisture than cold air. 6. When water vapor is cooled sufficiently in the atmosphere, it condenses and falls as rain or snow. 7. Four different kinds of clouds may be seen in the sky. They are called cirrus, cumulus, nimbus, and stratus. 8. Fog, dew, and frost are formed when water vapor condenses. 9. Sleet and hail are frozen rain. 10. Lightning is a huge spark of frictional electricity. 11. Thunder is caused by air rushing back together after lightning has passed through the air.	How do we measure the temperature? How do we measure air pressure? How can we measure the amount of water vapor or moisture in the air? How can we determine the direction the wind is blowing? How can we measure the speed or velocity of the wind? How can we measure the amount of rainfall? How can we use the weather instruments in a classroom weather bureau? How can we have a healthful climate in our classroom? What are some of the causes of the weather myths, sayings, and folklore? 1. Weather is the result of a cycle of cause and effect. 2. Climate is the general average of weather over a large area. 3. The weather is forecast after a careful study is made of facts collected by many different weather instruments. 4. Weather has a definite relationship to man and his environment. 5. Weather lore consists of statements, not based upon scientific fact, which have been passed from one generation to another and used as means of predicting weather. Many of the ideas in weather sayings are false. A few of them are true.

Methods commonly used in teaching science to children

The children who have experienced rich opportunities to study science have engaged in a variety of ways of learning. In fact, the richness of their programs was related in part to the variety: variety of questions dealt with, variety of materials and resources used to gain information, variety of ways of applying knowledge gained. Methods were selected insofar as possible to meet the needs of individual children. This means that a particular question

*TABLE 11-3 Content organization, type 4 **

Grade 1.	Our homes and how we live in them
	How we go to and from school and what we see on the way
	How we enjoy our pets
	Our school and how we live in it
	Holidays and special days
Grade 2.	Getting acquainted with our community
	Workers in our community
	How our farm neighbors help others
	Holidays and special days
Grade 3.	The everyday things about us
	Where the people in our community work and what they do
	How people learn what other people are doing and thinking
	How man uses water and how it affects him
	The Indians who lived here before us
	Holidays and special days
Grade 4.	How people live and work in our county
	How people live and work in our state
	How plants and animals help or harm each other
	How people live and work in other lands
	Neighbors in space
Grade 5.	How trade and travel lead to discovery and exploration
	Why the northeastern part of our country is called "The Changing Northeast"
	How man learns about his environment
	Why people settled in the South and how modern machines built a "New South"
	Why people moved into the agricultural interior and how they developed it
	Why the western states have grown so rapidly
	Parts of our nation that may someday become states
	Our common interests with Canada
	Holidays and special days
Grade 6.	Composition of substances
	Our nearest neighbors to the South
	How weather changes and how we predict weather
	How the nations of South America have developed
	Transportation and communication in the Americas
	The growth of American institutions
	Holidays and special days

* *The Elementary Course of Study,* Bulletin 233 B, Department of Public Instruction, Harrisburg, Pennsylvania, 1951

or problem or topic was approached by children in different ways, some studying one aspect and some another.

In such programs children did not follow a lock step approach in which everyone necessarily studied the same details at the same time in the same way.

In order that the learning experiences had maximum value (so that

"variety of activity" did not mean disorganized and aimless activity), much planning by teachers and children took place: What are the things we want to know? What shall we find out first? Who does and who does not already know about this? Who needs to do further investigation on this question? How can we get the information we need? Will we use books? Field trips? Films? Experiment with materials? Talk to people who already know? Which things will we all do together? Which individually? When will we do them? A trip? Who will help plan it? An experiment? What materials will we need? Where can we get them? What have we learned? Have we arrived at some new understandings? How can we make use of this information? What do we need to study further?

Yes, in a rich science program children had opportunities of the kind suggested by the dozens of questions above. In such programs the teachers have been very resourceful—but not so resourceful that they did all the planning, obtained all the equipment and materials, did all the reading, and told the children all the answers! On the contrary, they kept in mind that the methods used must give support to the major purposes of helping children *learn how to learn, think critically,* and *develop an awareness of how knowledge is obtained* by getting it through many and varied experiences.

Thus children in good scienre programs have learned through exploring and investigating with all their senses, using all kinds of available learning resources. And in all this they normally have acquired a great amount of knowledge. But it would be a mistake to think that all of them acquired the same knowledge. Most elementary science programs were aimed not at having all children acquire the same knowledge, but at having all children increase and mature in their knowledge. Some will have gained a tremendous amount; others will have gained much; still others will have gained little.

To be realistic, the existence of a state or local science curriculum is no guarantee of what actually occurred in the classroom. Many elementary teachers are insecure in science; they need quite a few types of help and encouragement from able consultants. In many schools the methods used were less stimulating and the science programs limited. Perhaps "reading about science" with an occasional demonstration was the typical pattern. Perhaps children did not have an opportunity "to try things out for themselves" as often as necessary, either to maintain interest or to gain understanding. Perhaps "science time" was the period when a few selected children performed for the others, without much opportunity for those "others" to participate. Perhaps science was something children were permitted to read about after they had completed their other lessons. But for some, it was hard to complete these other lessons; so there was no science, except for the quick students.

Regardless of the particular kinds of experiences which pupils now in high school science classes had in elementary school, and the present status of methods used in teaching elementary science, there is no doubt that year by year the programs are improving. Everywhere elementary teachers are anxious and striving to improve their knowledge of science and skill in teach-

ing it. Ideally, it is hoped that most high school science teachers can assume with confidence that the children they teach have been taught in elementary science "in the ways of the scientist."

In regard to methods used, the challenge to science teachers in the junior high school and the high school is at least twofold. First, they dare not let down those pupils who have already come to know science as an opportunity to investigate and inquire in a variety of ways. They dare not take a chance on approaching the study of science, for example, from just reading and talking about it. This would certainly be dull, boring, and disillusioning to young people who had sprouted wings in the methods of science.

The second challenge is to give pupils who have *not* had rich experiences in the methods of scientific investigation opportunities to study science in ways that will spark their imagination and enthusiasm. It is the purpose of this book, of course, to present in many contexts suggestions which will enable high school science teachers to meet both of these challenges.

Some characteristics of children and how they learn

In rich science programs in the elementary school, children used a variety of methods and materials, as described in the foregoing section. There is perhaps no virtue in variety for variety's sake. But the necessity of variety of approach, of materials, and of methods seems to follow from our knowledge of the varied interests and abilities of children and how they learn. By a "good" science program we mean one in which these variations are taken into account.

Children are investigators. Children ask questions, they feel objects, they touch and smell things. This trait of curiosity is in itself a sufficient basis to justify a good science program in the elementary school. And though there are many common elements among children's questions about their environment, there is also diversity. Thus, in order to nurture interest and help children know about things that are of immediate concern to them, some schemes must be worked out to take into account the variety of interests among children.

Children learn through activity. The application of this principle in science teaching requires careful thought about what it is children are supposed to learn. Are they to learn to think carefully? Observe carefully? Plan procedures? Develop skill in using and caring for scales, microscopes, telescopes, rulers? Read for relevant information? It is usually intended that children learn these things. If so, it is these things which children need experience in doing. Thinking, reading, experimenting, etc., are *doing*.

The ability to wire a simple series circuit is not learned by most children without doing it many times. And wiring dry cells, buzzers, and switches in series helps most children understand the nature of a circuit better than simply reading about it or having it shown or described to them.

Children do different things as they learn. Some children may understand a simple circuit after reading about it without wiring up a circuit. Some may understand a point perfectly after hearing it explained; some need to see pictures; some need to read about it and talk about it; many need to do it. Thus the only safe procedure in working with groups of children is to give them opportunities to approach the learning through a variety of activities. All children may not need to do all things. Judicious guidance by the teacher, plus ample planning with the children, is the key to the organization of learning situations where children *do* what they *need to do* to learn best.

Planning has just been mentioned. Aside from the fact that we want children to mature in their ability to plan courses of action for themselves, toward appropriate ends, it is generally believed by elementary teachers that *children learn best when they understand the purposes for which learning activities are being carried on.* One way to get this understanding of purpose is to involve children in discussing the purposes and in planning ways of achieving them. In this way children are used as valuable resources; invariably good ways for their learning come out of the suggestions offered.

Good teachers are aware that successful science teaching depends on, and is promoted by, taking into account these characteristics of children and how they learn.

High school teachers' role in improving elementary science teaching

Every high school teacher is in a position to contribute either directly or indirectly to the improvement of science teaching in the elementary school. Four ways will be mentioned briefly.

Influence on prospective teachers. One of the most common reasons given by elementary school teachers for not teaching science is that they disliked the science they had in high school and were not interested in taking any more of it in college unless required. When they did take science courses in college, the experience often intensified their dislike of it. As a result they frequently have skimpy knowledge of science and a fear of attempting to teach it. Of course, this is an oversimplified explanation, but nevertheless there seems to be some truth in the remarks of teachers that their early experiences with science in high school influenced their outlook on teaching science. What are your obligations to children who may become elementary school teachers?

Big brothers and sisters have little brothers and sisters. When high school students who are taking science are enthusiastic about it, the enthusiasm spills over at home. Often there are younger brothers and sisters whose interest is sparked by learning about what is going on in the science classes in high school. More than one elementary school youngster has carried this interest back to his classroom. From this interest his entire class may get

launched on a series of investigations. Does this suggest ways in which your classes might be taught?

Helping elementary teachers with their science teaching problems. Almost every junior high school or high school science teacher has opportunities to help elementary teachers and children with their science problems. Sometimes it may be through helping classify a flower, a rock, or a shell. It may be helping make out an order list of materials to be purchased from a science supply house. It may be in going to the classroom and helping the children get launched on a science unit, or in answering questions for them, or in doing a demonstration which the children might repeat for themselves later.

Occasionally, upon request, the high school science teacher can arrange for his pupils to work with children periodically on science problems. Often the pupils (not too long out of elementary school themselves) can sense the kind of help that is most useful. In spite of this possibility, when older pupils help younger ones, it is usually wise for the teachers involved to be in on the planning and direction of the activities.

When the high school science teacher agrees to help a group of elementary school children, he must do it in the framework of the purposes of the group he is helping. Teaching the content and more exacting methods which high school pupils are expected to learn cannot be the program for elementary school children. But by keeping in mind what the science program of the elementary school is, the high school science teacher can be both a stimulation and a good resource for elementary teachers.

Serving as consultants in elementary school inservice programs and workshops. The high school science teacher is often asked to serve as a consultant at science workshops for elementary teachers, or as a committee member of a group planning a curriculum program for a city or county. When such an occasion arises a science teacher who understands the elementary school and how children learn science is in a good position to be helpful.

The development of science curriculums in most elementary schools is usually a part of an inservice program for teachers. Thus the development of the program for children is at the same time an opportunity for elementary teachers to become better prepared to teach science skillfully. When the high school science teacher is called upon to help, he can be most useful by beginning with the problems and questions of the teachers, and working with them in ways that stimulate growth in them and give them confidence.

Usually this means helping teachers plan experiences whereby they can discover knowledge for themselves (opportunities to experiment, to read, to take trips and the like) rather than the direct memorization of scientific facts from lectures and books. At least, as with children, discussion and books should be tied into the learning process along with other relevant sources of information. In short, teachers need opportunities to investigate for a purpose in the same ways they expect their children to investigate.

The science teacher serving as a consultant to elementary teachers is not most effective when his chief concern is "to prepare children for high school

science." Rather he is most useful when he helps elementary teachers consider reflectively what is best for the children concerned and when he helps them make science exciting and stimulating for those children. He is then, as a matter of fact, helping the children prepare for more mature interests in and study of science.

An excursion into elementary science

11-1. At your earliest opportunity visit several elementary science classrooms. If the elementary school feeds your junior or senior high school, why not offer your help? The elementary school science teachers may return this help by identifying the "science prone" for you.

11-2. For further reading:

Blackwood, Paul E., *How Children Learn to Think*, U. S. Office of Education Bulletin No. 10, Washington, D. C.: U. S. Government Printing Office, 1951, 19 pp.

Blough, Glenn O., and Paul E. Blackwood, *Teaching Elementary Science: Suggestions for Classroom Teachers*, U. S. Office of Education Bulletin No. 4, Washington, D. C.: U. S. Government Printing Office, 1948, 40 pp.

Blough, Glenn O., and A. J. Huggett, *Elementary School Science and How to Teach It*, N. Y.: Dryden Press, 1951, 495 pp.

Burnett, R. Will, *Teaching Science in the Elementary School*, N. Y.: Rinehart, 1953, 541 pp.

Craig, Gerald S., *Science for the Elementary School Teacher*, rev. ed., Boston: Ginn, 1958, 894 pp.

Dunfee, Maxine, and Julian Greenlee, *Elementary School Science: Research, Theory and Practice*, Washington, D. C.: Association for Supervision and Curriculum Development, 1957.

Freeman, Kenneth, *et al.*, *Helping Children Understand Science*, Philadelphia: Winston, 1954, 314 pp.

Greenlee, Julian, *Better Teaching Through Elementary Science*, Dubuque, Iowa: Wm. C. Brown, 1954, 204 pp.

Heiss, E. C., E. S. Obourn, and C. W. Hoffman, *Modern Science Teaching*, N. Y.: Macmillan, 1950, 462 pp.

Hubler, Clark, *Working with Children in Science*, Boston: Houghton Mifflin, 1957.

National Society for the Study of Education, *Forty-Sixth Yearbook*, Part 1, *Science Education in American Schools*, Chicago: U. of Chicago Press, 1947, 296 pp.

"Science in the Elementary School," *The National Elementary Principal*, Vol. 29, No. 4, Washington, D. C.: Department of Elementary School Principals, National Education Association, Feb. 1950.

Zim, Herbert S., *Science for Children and Teachers*, Washington, D. C.: Association for Childhood Education International, 1953, 55 pp.

CHAPTER 12

Inventions in science courses:

The course in biology

A note at the beginning: Biology courses are generally given in the tenth grade, following general science. The entering boy or girl has already studied considerable biological science; he has had it in elementary science and in general science. Yet here is his first experience with a useful body of information with its own particular flavor.

Sooner or later a teacher, say, a teacher of biology, begins to wonder about the course he is to teach or has been teaching for years. Perhaps a new course of study, a new syllabus comes to his attention or a new textbook arrives. Perhaps he is on a curriculum committee to work with others; perhaps he is a free agent and can build his own course if he wishes. To what is he to turn for suggestions?

The teacher is not alone. Others have worked before him, and he can build on what has been done, on material, for example, in this chapter and the readings it suggests.

This chapter, and the next three chapters are similar in structure; they are organized as follows: [1]

Development of the course in biology
Patterns of present courses in biology
Frames for developing a course in biology
Special considerations in teaching biology
An excursion into developing one's own course in biology.

Development of the course in biology [2]

The first secondary school botany and zoology courses, from which biology has evolved, were patterned after college courses. (To develop the exact

[1] Substitute "chemistry" or "physics" or "general science" for "biology" in each of these headings for the subsequent three chapters. Chapter 16, The Course in Physical Science, does not follow this pattern, the course is too recent to examine in the same way or at such length.

[2] This section draws from S. Rosen, "The Decline and Fall of High School Physiology," *School and Society*, 85, 308, 1957, and "A History of Science Teaching in the American Public High School, 1820-1920," unpublished Ph.D. thesis, Harvard U., Cambridge, 1955

line of course changes is not necessary, for the college courses in botany and zoology a century ago were rather different from courses of the same names now.) A secondary school course in "natural history" was introduced around 1818 in the Wesleyan Academy in Wilbraham, Mass. A similar course appeared in the New York City curriculum around 1825. The first physiology courses seem to have appeared in schools shortly after 1825. Natural history, although somewhat haphazard in its choice of materials (which depended upon the interests of the individual teacher), nevertheless, was minutely detailed, stressing taxonomy, anatomy, and later, comparative anatomy, with emphasis on nomenclature. Separate botany and zoology courses were the common pattern, with physiology a later addition. After 1850, of the three courses, botany and zoology seem to have been offered by about half the secondary schools, while physiology was available in more than three-fourths.[3]

The flavor of these early courses can be sensed from the books available. In 1875 Edward S. Morse wrote in the preface to his *First Book of Zoology*, ". . . the pupil is expected to study with the book in one hand and the specimens in the other."[4] The appeal was for systematic classification through careful attention to static attributes of the material. Few concepts were involved, for biology still lacked many of the major concepts available today.

The characteristics of these courses at the turn of the century are indicated by the recommendations of the Committee of Ten in 1891 for a year's study in high school of botany or zoology. Botany was preferred because appropriate materials were readily available in the local environment. The course was to be concerned with "minute anatomy and classification" through direct observation.[5] The approach to zoology is indicated by this realistic statement:[6]

> Success in teaching [zoology] is sometimes jeopardized by the early presentation of disagreeable features of the subject matter taught. It is desirable to postpone the consideration of these, if it can be done without essential loss, until the interest of the student has been so secured as to induce him to face the disagreeable for the sake of probable, though distant, advantages. Hence everything like dissection should be postponed until the eager curiosity of the tyro overcomes a possible timidity incident to anatomical investigation.

At the dawn of the 1900's we find then the structure: separate botany and zoology strongly dominated in subject matter by Linnaean minded naturalists and in pedagogy by faculty psychologists. Both dominating influences were to be rudely shaken, the former by Pasteur, Darwin, Mendel, Bateson, and Huxley, the latter by experimental psychologists like G. S. Hall, Thorndike, Thurston, and even Freud.

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[3] Exact data are not available on the frequency or enrollments in these courses. The statistics of the U. S. Office of Education do not include physiology until 1900 or botany and zoology until 1910 although these courses had been offered for decades.

[4] Edward S. Morse, *First Book of Zoology*, American Book, N. Y., 1875, p. iii.

[5] *Report of the Committee of Ten on Secondary School Studies*, American Book, N. Y., 1894, p. 137.

[6] Ibid., p. 334.

Huxley had already introduced a course called biology in the 1850's; soon thereafter one of his students founded a similar course in Johns Hopkins University. In 1905 a New York course of study in high school biology appeared. Such first biology courses were inevitably a compound of physiology, zoology, and botany. Later materials were added, for one reason or another, from the fields of anthropology (evolution), geology (mainly historical), and psychology (mainly habits of study).

Then as now, syllabus committees were not as free as one might suppose; they were expected to give attention to the botany, zoology, and physiology of the past and to the genetics, anthropology, evolution, and psychology of the present. And the chemistry of living things (biochemistry) was beginning to deserve attention. By 1910 the process of fusion was widely accepted.

In 1913 the College Entrance Examination Board first offered an examination in biology; the syllabus for preparatory courses was, however, half a year of botany and half a year of zoology. Not until 1936 did this Board offer an examination in unified biology. Evidently the schools were ahead of the colleges and their Entrance Board in designing effective high school courses.

In 1920 the Commission on the Reorganization of Science in the Secondary Schools suggested[7] that biology be offered in the ninth grade in schools organized on the 6-3-3 plan and in the tenth grade in schools organized on the 8-4 plan. Soon biology was generally offered in the tenth grade as it customarily is today. Botany and zoology courses are, for all practical purposes, not significant in the present secondary school curriculum. Physiology courses still have an appreciable enrollment, but generally they are now offered as an advanced biology course for students interested in nursing or home economics.

The biology course today, if we are to take the judgment of the Forty-Sixth Yearbook Committee,[8] indicates that "the trend has been toward focusing attention less on the organization of subject matter and more on the results in the lives of the learners." Materials significant to the child have been substituted for traditional material which had little relationship to the world in which the youngster lived.

Part of the reason for the rapid shift of the course in biology from the traditional base in zoology and botany has been the elimination of the double laboratory period, once an essential component of courses in botany and zoology. Indeed, the biology course is currently noted for the fluidity of its laboratory period. On the other hand, courses like chemistry and physics, with a fixed laboratory period, tend to retain a traditional body of material because they retain traditional equipment and a fairly continuous structure.

More important probably was the fact that biology was given in the tenth grade to a body of students with vastly divergent gifts and potentialities. Hence there was need for a course to serve a large undifferentiated group.

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[7] *Reorganization of Science in Secondary Schools*, U. S. Office of Education Bulletin No. 26, Washington, D. C., 1920.

[8] National Society for the Study of Education, *Forty-Sixth Yearbook*, Part 1, *Science Education in American Schools*, U. of Chicago Press, Chicago, 1947, p. 184.

In any event, biology has developed not in the tradition of a course for a selected group—selected by whatever device one chooses—but as a course identified with general education. It looked first, in short, to the development of human beings, and secondly, to the development of specialists; first it dealt with life, then with college entrance. The primary criterion for assessing a course for all pupils is simply: Will the course result in more intelligent behavior?

In 1931 the *Thirty-First Yearbook*[9] had stressed not only that courses should be organized around the principles of science (not separate details of subject matter), but also that these principles should relate to everyday living. Cole[10] in a textbook on the teaching of biology stressed the need to make biology meaningful in the lives of students; "knowledges, skills, experiences, and concepts in life situations" were at the core of biology teaching.

Put more specifically, biology teaching in the early 1900's provided specialized training far in excess of the needs of the children of the community. This type of teaching dealt with a content ("minute anatomy and classification") which was often so unrelated to problems of living that it became useless, boring, and impossible to remember. It seems difficult to justify requiring the majority of our students to learn the complete life histories of *Paramecium* (heteromixis, for instance), *Rhizopus*, and *Spirogyra*, and the alternation of generations in the mosses and ferns, and to memorize the extensive scientific vocabulary involved in the classification of plants and animals, when the urgent and immediate problems of personal and community living—nutrition, disease, social behavior, racism, and biological production—begged for attention. However, that this was once the case can be understood if we recall that in the early 1900's faculty discipline was the basis of the psychology of learning, the high schools still had a limited enrollment of students preparing for college, and science teaching was in its infancy.

It appears now that the trend[11] in the teaching of biology is toward dealing with the concepts of biology which will help students understand themselves as organisms and their environments in terms of the interrelationship of the organism and the environment. The trend is to fit biology to the needs and interests of all students, whether academically able or not. Hence the multiplicity of courses.

In general, biology teachers do not exclude from their course any given group of students. From the modern biology course all students might gain:

1. A sufficient understanding of the concepts of biology to enable those who will not become doctors, nurses, veterinarians, farmers, or other agents of public health or biological production to cooperate intelligently with those who are.

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[9] National Society for the Study of Education, *Thirty First Yearbook*, Part I, *A Program for Science Teaching*, U. of Chicago Press, Chicago, 1932.

[10] W. E. Cole, *Teaching of Biology*, D. Appleton Century, N. Y., 1934.

[11] This trend appeared from a study of 10 best-selling textbooks in 1935 and in 1955, also from a study of curriculums in 72 varied school systems, small and large, rural and urban

2. The opportunities for a practical understanding of the method of the biologist which will give them the confidence, in consultation with experts, to attempt the solution of problems which they have to face in their individual and social lives.

3. The incentive to become biologists (scientists with special interest in biology) or experts in applying the concepts of biology (e.g., doctors, nurses).

If this interpretation of the trend in modern biology teaching is correct, one would expect to find a wide variety of courses, including those for the science-shy and for the science prone, this is indeed the case.

Certain biology teachers have attempted to fit their courses to an expanding and diversified student body. Enrollments in biology have tended to include a majority of the students.

Brown[12] reported that in 1954-55 enrollment in all types of biology courses equaled 72.6% of the number of pupils enrolled in the tenth grade. Nation-wide this percentage ranged from 60.8 in the Pacific states to 87.7 in the South Atlantic states. Average class size in biology was 27, in contrast to 22 in chemistry and 19 in physics. Of those schools with tenth grades, 89% offered biology.

The significance of the 72.6% enrollment in biology increases when we note that chemistry enrollments equaled 31.9% of all eleventh graders, while physics enrollments equaled 23.5% of all twelfth graders. In total pupils biology had three times the enrollment of chemistry and four times the enrollment of physics.

The percentage of public school children in biology has increased steadily since its introduction, at the expense of botany, zoology, and physiology. In 1910, for instance, the total number of students enrolled in the new biology course was only 8,000, although 280,000 others were enrolled in botany, zoology, and physiology. In 1955 biology enrolled 1,200,000 pupils, an increase of 150-fold since 1910, or 19.6% of all children in high school. The biology course, newborn in 1910, has become a stalwart member of the science curriculum.

As a consequence biology teachers have the opportunity of reaching and influencing many more students than either chemistry or physics teachers. The type of course offered in biology is then especially important.

Patterns of present courses in biology

There are various course outlines (scope and sequence material) available which we should examine before we develop a base for the particular one which the reader may devise for his own purposes. At all times the samples

[12] Kenneth E. Brown, *Offerings and Enrollments in Science and Mathematics in Public Secondary Schools*, U. S. Department of Education Pamphlet No. 118, U. S. Government Printing Office, Washington, D. C., 1956.

offered here are to be considered not as "models" or "examples," but just as *samples*. A scope and sequence is a *curricular invention* which fits a *particular* group of students, in a *particular* school, in a *particular* community. That invention is the result of the collaborative efforts of *particular* teachers with *particular* training. Hence one scope and sequence should, and indeed must, be different from another. There are, however, families of course outlines which bear general resemblances to each other.

Inevitably with the changing numbers and composition of high school enrollments and the changes in teachers' views of their responsibilities to the pupils, course design in biology has taken several different centers of concern. These came historically in a sequence and most are still with us in varied abundance. If you observe in the schools of the country, you will discern patterns such as the following.

The systematic, or college-preparatory, course

Systematic courses, often with half a year of botany and half a year of zoology, were among the first to be offered when biology appeared in the curriculum. Because these mimicked collegiate courses and because, at that time, all courses were heavily college-oriented, these were often known as "college preparatory." A diminishing number of public schools give such courses,[13] although they are still rather common in the private schools which stress college preparation.

Table 12-1 shows the parallelism between systematic biology courses in high school and in college. Column 1 gives a course outline for a biology course in high school; column 2, for one in college. Obviously the intent of such a high school course is to present the subject matter of biology systematically. This "college-preparatory" course in the high school may be identical in intent certainly, and even in content, to a college course, or it may be "watered down." In either case, the lecture method is generally favored; for, if all the material is to be *covered* in class, no other teaching procedure will suffice.

The evidence is scanty indeed that the subject matter content of a course is in itself a significant factor in preparing students for general success in college or even in a collegiate course within the same field. Such courses may, however, help prepare students for the examinations of the College Entrance Board, insofar as teachers can determine by one means or another what these examinations include. This idea of "preparation for examinations" deserves and will receive careful scrutiny in Chapter 19.

Why such systematic courses are still fairly common in the high school is puzzling. They cannot be justified as preparation for the College Entrance Examinations; less than 10,000 (in 1954-55 actually 7,025) of the 1,200,000 pupils

[13] In a survey in Michigan, G. G. Mallinson found about 40 per cent of the biology courses to be "systematic." (Newsletter 2 of the Michigan Science Teachers Association, June 1955, mimeographed.) Several of the texts in high esteem are constructed on this pattern.

TABLE 12-1 ***The systematic biology course in high school and college***

High school *	*College* †
I General characteristics of life A Scientific method in biology B Characteristics of living things C Classification of plants and animals D The cell (protoplasm)	I General characteristics of life A Science and biology B. Chemistry of protoplasm C The cell D Characteristics and functions of living things
II Plant life A Schizophytes, thallophytes B Mosses C Ferns D Seed plants E. Plant physiology	II The plant kingdom A Thallophyta B Schizomycetes C. Bryophyta D Pteridophyta E The evolution of sexuality in plants F Gymnosperms G. Angiosperms H Anatomy of plants I. Physiology of plants J Ecology of plants
III Animal life A. Unicellular animals B Lower invertebrates C Higher invertebrates D. Lower vertebrates E Higher vertebrates F. Ecology (plants-animals)	III Invertebrates A Protozoa (protista) B Coelenterata C. Platyhelminthes D Nemathelminthes E. Annelida F Arthropoda G Mollusca
IV Animal anatomy and physiology A The digestive system B The respiratory system C. The circulatory system D The nervous system E. The reproductive system F The excretory system G Endocrines	IV. Vertebrates A. Protochordates B. Chordates C. Animal metabolism D Type forms (frog, rat) F. Digestive systems F. Respiratory, excretory systems G. The circulatory system H Sense organs and the nervous system I. Endocrines J Reproductive systems
V. Embryology and heredity A Development B Heredity	V. Ecology A Ecology of plants B Ecology of animals C. Economic biology
VI Evolution A. Geological history B Theory of evolution C. Mechanics of evolution	VI. Development A Types of development B Physical base of heredity C. Human heredity D Plant and animal breeding
VII. Optional A. Biological professions	VII. Evolution and man A. History of life B Organic evolution (theory) C. Evidences for evolution D Mechanism of evolution E. Biogeography and man

* From two high schools, one in New England, one in a Middle Atlantic state.

† From a Midwestern university.

TABLE 12-2 The principles course in biology *

I. Life functions of organisms	IV. Living things react to their environment
II. Living things vary	A. Behavior
A. Organization	V. Plants and animals resemble their ancestors
B. Classification	A. Genetics
III Living things depend on their environment	VI. Life has continuity
A Food getting	A. Reproduction
B Photosynthesis	VII. Life is a result of organic change
C. Interrelationships	A. Evolution
D. Conservation	

* Typical of courses given in five cities. Northeast, Southeast, Midwest, Southwest, Northwest The order of units varies.

enrolled each year in biology take the College Board Examination in it.[14] But they indicate the influence of the college on the high school.

The principles, or conceptual schemes, course

In time, more and more students remained in high school, and as the course in biology continued to develop from its base in botany and zoology, it evolved along the lines of general education. Increasingly teachers developed their courses in the ninth and tenth years to help young people understand the world about them. This meant emphasis on the major principles of biology, on the life functions which were generally those of all organisms, on information which could be applied generally. Hence, there was emphasis on the major generalizations or principles which describe how the organism behaves or how it has changed with time (see Table 12-2). The emphasis was not on invertebrates and vertebrates as such, but on the *principle* of evolution which underlies their development. The characteristics of vertebrates were used to shed light on the evolution of organisms.

However, the "principles course" as developed in high school was never really a *principles* course. The relationships central to the course were of diverse degrees of generality. Sometimes they were found in processes or functions such as respiration, reproduction, digestion; while at other times they were taken from such embracing ideas as evolution, conservation of energy, and the food cycle. The functions of plants and animals, like reproduction, were often related in one curricular block or unit. Yet the larger principles underlying such relationships (e.g., the principle of the alternation of generations evidenced in the evolutionary development of organisms) were rarely developed. Apparently a course treating really grand principles of biology remains to be developed for the high school.

[14] H. S. Dyer and R. G. King, *College Entrance Test Scores and Their Interpretation*, No. 2, Educational Testing Service, Princeton, N. J., 1955.
Fifty-Fourth Annual Report of the Director, College Entrance Examination Board, N. Y., 1956, p. 62.

TABLE 12-3 A needs-centered course in biology*

I Improving our behavior	V Improving our food supply
A General behavior	A Photosynthesis
B Learning	B Conservation
II Living a longer, more vigorous life	VI Biology in our personal lives
A Health	A. Recreational (field trips)
B Disease	B Hobbies
C Diet	1 Animals
F Longevity	2 Plants
III Our inheritance	3. Pets
A Heredity	C. Vocations
B. Evolution	1 Medicine
IV Getting along with others	2. Nursing
A. Anthropology	3. Technology
B Racial relations	

* From two courses, one given in a West Coast city, another on the East Coast.

The needs-centered course

Almost at the opposite pole from the course in systematic biology is one which might be called "needs centered." Its content is derived from an examination of the behavioral objectives to be sought from general education (Chapter 5). Its foremost objective is to provide whatever biology young people really need to know and utilize for successful living.

The course draws its content from all of biology. It attempts to get boys and girls to state their "problems" and to seek answers through building and applying relevant concepts. For instance, if a boy or girl were to ask, "How can we know whether feeblemindedness is inherited?" the concepts of heredity and many others would be involved in the search for a solution. If the teacher is the type who plans with the class (Chapter 4), then he would ask the class, "What do you need to know to answer this question?" and proceed to develop a series of concepts or principles, as well as activities, which would help students solve the problem. (Note on page 241 the value of such a course in leading to high scores on the College Entrance Examination in biology.)

The importance of attempting to discover and deal with the real needs of pupils (among other significant points) was underlined in the "Report of the Southeastern Conference of Biology Teachers"[15] held in 1951: "The objectives of the course are not valid until they become the objectives of the students." Teachers who believe this find their objectives most readily *by beginning with those of the students* within the area of biology and by adapting the subject material and interweaving the concepts required for satisfying answers. The objectives or "problems" of the students will show considerable stability from year to year and place to place.

Whether the course is evolved by planning with the children or by a committee of teachers sensitive to the interests of their pupils or by the

[15] *The American Biology Teacher*, Vol. 17, No. 1, Jan. 1955, p. 35.

TABLE 12-4 A compromise course in biology *

I. Introduction to biology
  A. Introducing the science of biology: The ways of the scientist
  B. The nature of life
    1. Characteristics of protoplasm
    2. Cells
    3. The organism
  C. The variety of living things
    1. Classification †
    2. Economics and ecology of living things woven in with the classification
II. Body structure and functions
  A. Structure and functions of plants
  B. Structure and functions of animals
III. Human biology
  A. Nutrition: Digestion
  B. Physiology
    1. Circulation
    2. Respiration
    3. Behavior
  C. Disease prevention
    1. Bacteriology
    2. Immunology
IV. Continuity of living things
  A. Reproduction
  B. Heredity
  C. Evolution
  D. Conservation

* Course from a large city school.
† One wonders why classification is taught so early in the course where it has little meaning. *Taught as part of organic evolution—as an outcome of it—and as lending evidence to this conceptual scheme, it does have meaning.*

Curriculum Coordinator is not important. The course has a distinct flavor different from those we have called "systematic biology" and "the principles course." One course based on children's interests is shown in Table 12-3.

The compromise course

Usually the course in biology as outlined in published curriculums of state or city departments is not entirely a "needs-centered" or "systematic" or "principles" course. A state or city department has many types of schools within its purview; hence, it generally prescribes not a rigid course but a course of study which permits many shades of opinion to survive. Generally, such a published course includes about 90 per cent of the topics the teachers in the state will teach. In fact, the outline of units in Table 12-4, included here as a sample of such a course of study, has 90 per cent of the topics generally taught in the entire country.

Which of these many topics are to be emphasized is indicated through suggested time allotments. For instance, by assigning the number of days in which each topic is to be "covered," or by indicating that some are "optional," relative emphasis may be placed on particular topics. Of course, if there is a state examination, its own emphasis will weight the various topics. One may expect that in such a compromise course, time is of the essence, and compromise is effected in the "teaching methods" used. The lecture dominates, although there is some discussion of "problems," particularly in Parts III and IV. Laboratory manuals and a workbook are customarily used. Essentially this course is an evolutionary link between the "systematic" and the "principles" and the "needs-centered" course.

The vocational course and the home economics course

In some schools, the vocational aspects of biology are stressed. There are such courses as gardening and biological laboratory techniques. Examples of these courses are available in special schools, for instance, in vocational schools. Similar in aspect to the vocational course is the biology course with the home economics approach, such as nutrition or nursing. Sometimes these courses are under the direction of the Health Education Department (see references at the end of chapter).

The honor course

Recently in an attempt to meet the needs of the more able student, or the rapid learner, honor courses in biology have been set up. These and other "honor courses" are discussed in Chapter 9. Such courses generally seem to be high school courses with *more* work than the "average" high school student does, or college courses with *less* work than the "average" college student does.

Frames for developing a course in biology

Eventually a teacher develops his own course and its pattern of activity. To what may he turn for help? When building a course he may wish to refer to the following frames of reference: all are important, but their order of treatment here may not be their order of importance to him. Since his course will be a personal invention, its special ingredients will involve his total teaching situation: students, teachers, and the community.

Conceptual schemes as a frame of reference

Depending on the structure of the course, the principles and concepts selected will form a pattern, but there will also be underlying conceptual schemes. This is inevitable, because science is a quest for the large concepts which explain the way the world works and which can be used for the design of further observations and experiments.

Biology has many conceptual schemes which give it a distinct identity as a science. For instance:

All living things originate from other living things.
Over geologic history, all living things have developed from simpler living things.
Cells are the building blocks of living things.
Genes (in their chromosomes) are the physical basis of heredity.
Living things get energy for their activities from their environment.
Living things live in communities.
Living things are mutually interdependent.

These conceptual schemes, and others the teacher may select for treatment in his course, may be subdivided into supporting principles, or concepts. For instance, let us take the conceptual scheme: Genes (in their chromosomes) are the physical basis of heredity.

Some concepts, but certainly not all, which might be included are:

Genes are transmitted to offspring through germ plasm, not through somatoplasm.

Chromosomes undergo a regular behavior during cell division (mitosis and meiosis).

Genes act as units in inheritance.

The genes affecting a single trait segregate into different germ cells during maturation.

Naturally, there are many others; the teacher will select those which fit the objectives of the course and those which fit his pattern.

Some biology teachers feel that there is really only one conceptual scheme —evolution—and that all other conceptual schemes contribute in a subsidiary way as principles, ideas within this central conceptual scheme.[16] While the designation of one major idea or another in science as a conceptual scheme is somewhat arbitrary, we should re-emphasize the importance of the embracing conceptual schemes which are properly the center of any course. Published studies of the many principles inherent in biology can serve as guides to the teacher who wishes to explore possible course reorganization.[17]

Sometimes in the construction of courses around conceptual schemes or principles, the major headings are stated in topical form. If this is done, we suggest that for clarity and emphasis the major concept be immediately stated after the topic, at least in the teacher's notes:

The Structure of Living Things: Cells are the building blocks of all living things.

The Reproduction of Living Things: All living things originate from other living things.

Communities of Living Things: Living things are mutually interdependent.

Inheritance of Living Things: Genes are the physical basis of heredity.

Evolution of Living Things: All living things have developed from simpler living things.

The reason is this: A topic indicates only an area of discussion, not where

[16] For an example of this in a college course see: G. G. Simpson, C. S. Pittendrigh and L. H. Tiffany, *Life: An Introduction to Biology*, Harcourt, Brace, N. Y., 1957.

[17] See, for example, W. Edgar Martin, *The Major Principles of the Biological Sciences of Importance for General Education*, U. S. Office of Education Circular 308, Washington, D. C., May 1948, "A Chronological Survey of Research Studies on Principles as Objectives," *Science Education*, 29, 45, Feb. 1945, and "A Determination of the Principles of the Biological Sciences of Importance for General Education," *Science Education*, 29, 152, April-May 1945.

the discussion is to lead The concept is a major idea to be built—an answer—which gives direction to the development of the topic.

Problems as a frame of reference

When teachers first tried to frame their courses in terms of children's interests, course structure was stated in terms of problems, real or contrived. Such courses were often built on the assumption that the problems which would arise in the classroom were the formal, academic problems to which biology had an answer. They were such problems as:

How do living things reproduce?
How do living things fight disease?
How do green plants make food?
How do living things depend upon each other?

These, however, are not children's problems, but principles or concepts pressed (even distorted) into question form. They are artificial and permit the teacher to present the former "principles course" under the guise of involving pupil interests and questions No one, except possibly the teacher, was fooled by this formulation of pseudo-questions.

This was not at all what curriculum makers meant by a course devoted to children's problems. But we are all familiar with the way courses are revised too often and too hurriedly. Sometimes, and this is sadly true, it is mainly the sentence structure within the course plan which is modified.

But there are real obvious problems of living. When these are recognized, the course content and format may undergo considerable alteration. Consider a course to be built around these "problems":

Why do we behave as we do?
What kind of food is needed for the best growth?
How can we grow the best food?
Why are we unlike our parents if we inherit our traits from them?
Is there a "superior race"?
Can a person's intelligence be changed?
Is insanity inherited?

These are the real questions children, and adults too, ask. In terms of carefully structured scientific concepts, these are "untidy" questions. But their answers involve much knowledge and many diverse concepts in new interrelationships. Very likely the information (subject matter) required to reach acceptable answers to these questions will differ considerably from that involved within the frames of reference previously described. The search for answers may not follow the academic structure of biology, or any other science, but then few of life's real problems *fit with* the structure scientists have used in organizing their results. If they did fit, they would not be problems.

What might you do under the question, "Can a person's intelligence be changed?" Probably you would include concepts dealing with evolution, heredity, behavior, and certain aspects of body physiology (hormones). This is not as "neat" as a formal structure based essentially on conceptual schemes. Yet, for an answer, considerable information must be learned; more important, it must be evaluated and structured by the student for his *own* answer to the question, *since there is no definite answer.* Different pupils may end with answers different in both degree and kind. This is proper so long as each is based on adequate information and cogent reasoning, always with the understanding that not all the evidence is yet in.

Needs and interests as a frame of reference

Yet another frame of reference results from a course built around mutual planning by student and teacher. The course will almost certainly have some of the "personal" problems noted above.

But in addition to such important questions as "Is there a 'superior race'?" and "Why do we behave as we do?" there will also arise in the course such special topics of personal interest as:

Understanding the meaning of I.Q.
Vocational testing.
The breeding of tropical fish.
Building a nature trail.
Hunting fossils.
Desert plants and animals.
The sea and its inhabitants.
Diseases in farm plants (corn, oats, apples).
Heredity in cats.
Races of man.

The approach to such a course was described in Chapter 4; it is the teaching method of Mr. P. If you are interested in determining whether this frame of reference can be useful to you and to your particular group of pupils, perhaps you will want to refer to Chapters 4 and 5.[13]

Objectives as a frame of reference

Finally, it is clear that the objectives which are acceptable to the teacher will condition not only the structure of the course, but the content, and certainly the way the course is taught.

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[13] See also Robert J. Havighurst, *Developmental Tasks and Education*, Longmans, Green, N. Y., 1950.
Educational Policies Commission, *Education for All American Youth*, National Education Association, Washington, D. C., 1944.
American Council of Science Teachers, National Committee on Science Teaching, *Science Teaching for Better Living*, National Education Association, Washington, D. C., 1942.

For instance, if his primary objective is to prepare students for college, the teacher may choose to give a course which is patterned after a standard college course (see Table 12-1). This course will have the earmarks, in many instances, of a fusion of zoology, botany, and physiology. A college text may even be used.

The students will then be prepared for a college course in the subject, but only in the sense that it will be determined:

1. Whether they can memorize material in a context unrelated to their lives.
2. Whether they can master a college text before they are in college. (This would be, some would hold, a fair indication of whether they later might "pass" the course in college.)
3. Whether they can learn well from the lecture approach, for such "college preparatory" courses are usually presented by lectures.

The teacher will have ignored what is known about preparation for college as found in a significant study.[19] He will also have ignored the thoughtful observations and advice in the Harvard Report[20] and other similar college statements. Essentially these studies and reports stress the point that the best preparation for college consists *not* in the details of the subject matter or the form of course organization, but in the experience a student gets in:

Communicating effectively.
Thinking with relevance.
Acquiring efficient habits of study.
Learning to work with others.
Discriminating between values.

Earlier we mentioned our preference for objectives in behavioral form: What is the boy or girl able to do as a result of the course and learning? If high school is to be the place where general education rather than special education is the goal, then we seek our aims in the test of efficiency. As Fitzpatrick put it:[21] "The test of efficiency is whether a given fact, concept, skill, or attitude will contribute to the development of more intelligent behavior."

Fortunately the biology teacher has at his command a study on behavioral objectives which should be of value.[22] If a teacher plans his year's work, his

[19] *Adventure in American Education*, 5 vols., Harper, N. Y., 1942-43, especially Vol. 4. Following are the volume titles
1. W. M. Aikin, *The Story of the Eight-Year Study*, 1942.
2. H. H. Giles, S. P. McCutchen, and A. N. Zechiel, *Exploring the Curriculum*, 1942.
3. E. R. Smith and R. W. Tyler, *Recording and Appraising Student Progress*, 1942.
4. D. Chamberlin, E. S. Chamberlin, N. E. Drought, and W. E. Scott, *Did They Succeed in College?* 1942.
5. *Thirty Schools Tell Their Story*, 1943.

[20] *General Education in a Free Society*, Harvard U. Press, Cambridge, 1945.

[21] F. L. Fitzpatrick, *National Association of Secondary School Principals Bulletin*, 37, 57, Jan. 1953.

[22] Will French *et al.*, *Behavioral Goals of General Education in High School*, Russell Sage Foundation, N. Y., 1957.

units (Chapter 17), and his daily work along the line of behavioral objectives, he will have, at the end of his first year's work in developing a pattern of his own, a practical beginning statement of objectives.

And, of course, biology is fun as well, "great fun," as some of the pupils say—especially when biology deals with living things, and with the most important living things in the classroom: themselves.

Special considerations in teaching biology

The flavor of the course

No matter what the pattern or the kind of course adopted, the course in biology has its special flavor, and its special problems.

Biology is essentially a study of living things and things that have once been alive. It is "living things" which give biology its special flavor and interest. It is "living things" which also present the biology teacher with his problems, for the maintenance of living things requires time and care. If the course encourages the young people in his class to take part in studying their own biology, the course not only concerns itself with a study of living things, but is alive as well—alive with the interests of young people in life and living. For instance, note the kinds of activities in the laboratory, in the field, and in the classroom which give flavor and fun to the search for meaning within a course in biology.[23]

Study of protozoa under the microscope.

Laboratory study of cells and tissues.

An experiment in blood typing.

A field trip to collect plants and animals for a terrarium.

Experiments in the chemistry of digestion.

A study of fossils (field trip and laboratory).

Experiments in photosynthesis.

Reproduction of plants and animals as studied through breeding of rats, culturing protozoa, growing yeast, discussion of human reproduction.

Analysis of soil.

Dissection of the frog and the rat.

Examination of one's own physiology.

The place of the laboratory in biology

This section will be brief. The laboratory in biology, aside from the special problems which characterize biology, is a science laboratory. As we have indi-

[23] See Section V, Tools for the Science Teacher, at the end of this volume, especially the sections dealing with laboratory procedure, the workbook, the textbook, and the field trip. More than a thousand other activities are given in the accompanying volume by E. Morholt, P. Brandwein, and A. Joseph, *A Sourcebook for the Biological Sciences*, Harcourt, Brace, N. Y., 1958.

cated in Chapters 1 and 2, the laboratory is a place for experience in search of meaning However, we do take special cognizance of a study of the place of the laboratory in teaching (Chapter 13) and in Section V, Tools for the Science Teacher, where we discuss procedures in the laboratory.

Terminology

Of all the sciences, biology is the one that is most readily loaded up with an enormous number of new terms, both English and Latin. To many children this vocabulary load is overwhelming; they cannot see the forest (sylva) for the trees (acer, pinus, quercus, ulmus). The question of how much specialized vocabulary to use is always with us. A reasonable answer seems to be: what is needed for the purposes, and no more. Biology students should know that a specialized terminology based on Latin is used world-wide for the precise identification of plants and animals. Yet for most of them a frog is a frog, perhaps a green frog or a leopard frog. Nicer distinctions are not likely to be necessary. In botany one can discuss a mountain laurel without terming it a *Kalmia latifolia* We prefer that children be acquainted with the real material and able to identify it with an English name in common usage, rather than that they know many technical terms, and are unable to identify the living material. If and when fine distinctions become necessary, the precise technical terms will be sought and remembered. At that time, the meaning of the Latin and Greek terms should be made clear: "latifolia" means "wide leaved." The same approach would apply to the complex internal structure of botanical and zoological specimens.

Generally a special name for a material or part should be introduced *after* the children see it and want a name that is better than "that thing."

"Controversial" topics

Problems with human significance can be ignored, especially in a rigidly scheduled, teacher dominated classroom. They are most easily ignored in a course based on systematic biology; they cannot be ignored, at least without a twinge of conscience, in the "needs centered" course. We wonder, too, whether any teacher may ignore, in good conscience, problems which arise out of the basic characteristics of the material he teaches. By way of example, consider these two teaching problems that arise natucally from studies of reproduction and evolution:

1. Shall we, in teaching reproduction, deal with the topic of human reproduction?
2. Shall we, in teaching evolution, deal with the topic of race? Of religion and its so-called "conflict with science"?

Are these problems within the purview of the biology course? We believe they are. And there are others. How shall we teach nutrition to children in low

income groups? How shall we consider the questions: is intelligence inherited? of what significance is skin color? what are the effects of environment on physical characteristics and on performance? The answers in the classroom will depend upon the teacher's training, personality, and methods; the nature of the curriculum, and of the student body; the character of the administration, and of the community.

Let us explore the significance of only one of these factors: teaching method. Where the lecture method is used almost exclusively, it is fairly easy to ignore these problems, or in dealing with them to sidestep controversial aspects. The teacher has assumed complete control for what is taken up and what is omitted in class. He can readily avoid "taking a stand" on almost any topic. The megaspores of the gymnosperms is a "good, safe" topic and desperately dull to children, but they have to take what is given, for the teacher gives the grades.

Where the discussion method is used and student participation is honestly encouraged, real problems arise in class. If a student asks a question, he has a right to an answer, but this need not be from the teacher. It may be sought through discussion, investigation, or reading. The teacher need not "take a position" at all. Here we have a clue to techniques useful in dealing with troublesome problems. When a student asks, for example:

Are there "superior races"?
Can intelligence be changed?
How do humans reproduce?

the question can be thrown back to the class in this manner: "Do you want to discuss this question in class, or do you want to investigate it by reading?" If the decision is for reading, then you must have at hand discriminating reading by various authors presenting different "sides" of the matter.

Suppose, however, that the decision is for discussion, and the topic is human reproduction. Perhaps after dissecting a frog and dealing with the reproduction of the frog, a student inquires whether human reproduction is like frog reproduction. (Whether they ask or not, many are probably curious about this question. If they ask, it indicates excellent rapport with the teacher.) Have you tried asking the pupils if they would like to deliver a baby pig, for "after all, it's very much like us"? We have found students eager to do this.

We get a pregnant pig uterus from a local abattoir or a supply house (see the directory of supply houses in Section V). Every four students get a piglet to "deliver." They dissect out the embryo, note the umbilical attachment to the placenta, the amnionic fluid, and other features.[24] At hand for ready reference are three or four books and perhaps a film on the reproduction of the pig, to be consulted for further details. As a question on human reproduction is almost certain in a biology class, the teacher can be forearmed. After the first

[24] For description of techniques, see the companion volume by Morholt, Brandwein, and Joseph, *A Sourcebook for the Biological Sciences.*

year, other classes will anticipate the opportunity of learning about what really interests them.

Other questions that will arise are like these: How similar is this embryo to the human? Is the human embryo attached somewhat like this? How does the growing fetus get its food and oxygen? How many sperms are needed to fertilize an egg? There is a "natural" reticence, developed by social conditioning, not to refer to coitus in the human, but to frame the basic questions in terms of the pig. As the two are so similar (in this respect, at least), transfer from one to the other is easy and reasonably accurate.

Another useful variation in teaching technique may also be used with topics of this type. Sometimes it is well to deviate from the position that the teacher is not to answer questions directly, but to throw them back to the class. Because some of the questions about reproduction may be embarrassing, because taboos have been set up, because students may feel uncomfortable in publicly inquiring about human reproduction and adult sex life, the teacher, where advisable, might want to give specific answers to (lecture) questions such as these, which have actually been asked:

Q. Can a man produce sperm indefinitely? Can a woman have children indefinitely?

A. Generally speaking, most women lose the ability to have children around the ages of 45 to 55, after their menopause. Similarly, most men lose the ability to produce active sperm a little later in life, probably between 55 and 60. A specific answer is difficult because the evidence is not adequate.

This procedure gives students confidence; they ask an honest question and get an honest answer. They see that "difficult" questions will not be ignored, even if the teacher must yield on a cherished teaching practice. Such mutual respect often leads to other very personal questions being asked, and answered, in private.

Nothing is gained and much is lost if "controversial" questions are avoided. The pupil's respect for the teacher and for teachers in general is undermined. He comes to feel that school is a place in which only certain topics are discussed. Usually it is not the "facts" under consideration that are "controversial"; these are generally well established. It is the *interpretation* of the facts for personal behavior which may be controversial. If the child comes to a place where he is obliged to make a decision, he will do it on the basis of the information and attitudes he has, irrespective of how adequate they are or where he acquired them. Surely, it is wiser to provide children with accurate information and then assist in developing the alternate lines of action and their consequences, than to leave them in ignorance. Always, however, care must be taken to maintain the teacher's creed, respect for the individual and the truth, with humility [25]

[25] When such topics are anticipated, mutual confidence and respect can be fostered by inviting an administrative or supervisory officer to the discussion. Parents, too, can be alerted and briefed on a pending topic so that they can cooperate at home. At least the shock of frankness and the distortions of pupils' abrupt comments can be avoided.

What can the teacher do when questions arise about the so-called "conflict between science and religion"? The apparent conflict is of course between varied interpretations of the facts within individuals rather than the facts themselves. Generally this will turn around a discussion of evolution. For many children this term has a limited meaning implanted by adults: "men came from monkeys." This is a gross distortion of the scientific meaning of the term and the grand concept it represents. Yet this is what many students bring to the classroom; their concept is meager, but they associate it with the verbal tag, evolution.

Much is gained by encouraging students to speak out in objection to "evolution" and then patiently drawing from them the statement that the principle of evolution is what biologists have developed as an explanation of the facts at hand. Then they can be asked: Would they want to be ignorant of what is "known," whether they agree with it or not? The fossil and anatomical evidence for successive changes of the plants and animals through geologic time, with more complex forms appearing later, is so overwhelming that all one needs is to have the students examine the facts; then they can draw their own conclusions.

One biology teacher whom we know taught in Tennessee shortly after the Scopes trial. The students defied him to teach "evolution"; of course, he "wouldn't do that, and anyway it was against the law." However, he soon had the pupils bringing in fossils from the limestone caves nearby, and *they* told him that the plants and animals must have changed with time. At the end, he could make the point that this general interpretation, rather than the idea of "men from monkeys" which they had rejected with strong emotional fervor, was what was meant by the label "evolution."

Ultimately the handling of controversial issues depends on the mien, manner, and ministration of the teacher. If be is calm, considerate, honest, good-humored, civilized, and ready to admit error, if he is permissive and not threatening, children will feel free to state their position, against all other comers in the class.

In the light of our discussion of the nature of "controversial" topics in biology, it is worth considering whether such a course can be given in the ninth grade. Are the students mature enough? Have they had sufficient experience with the intent and content of science? Have they had sufficient experience with the techniques the scientist uses to test bis preconceptions?

An excursion into developing one's own course in biology

12-1. Aside from your personal skills and wisdom gleaned from experience, aside from the notions gleaned from the references suggested in this chapter, aside from the ideas you have accepted as valid in your reading of the chapters

preceding this, you will probably want further help. It is readily available:

(a) *Syllabuses and courses of study* developed by other teachers, committees of teachers, or the professional staffs of the Curriculum Director's office. Usually these are quite detailed, for some a modest charge is necessary. We have at hand some 120 such outlines and courses of study which have been exceedingly useful in developing our own courses The state departments and cities listed here are some of the many throughout the country that have developed materials useful as guides to the development of your own "course invention." Certainly in developing your own course you need not start as if no other work had been done previously.

1. First be certain to write to the State Departments (state capitals) of selected states; address the Director of Secondary Instruction, or the Supervisor of Science. Each state has either materials directed at the secondary school (with some mention at least of the curricular direction in biology) or a special publication in science, with detailed reference to biology, or a biology course of study.

2. Useful materials can be obtained from the Director of Instruction or the Curricular Division of many cities; the following is a partial list: Atlanta, Baltimore, Boston, Buffalo, Chicago, Cincinnati, Detroit, Hartford, Indianapolis, Los Angeles, Miami, Minneapolis, Newark, New Orleans, New York, Oklahoma City, Philadelphia, Portland (Ore.), Raleigh, St. Louis, San Diego, San Francisco, Seattle, and Wilmington (Del.).

3. The aim of the professional science teacher should be to gather personally or through his Department an extensive library of recent courses of study. These will necessarily be renewed continually. Among the sources from which you can learn of new curricular publications are:

Association for Supervision and Curriculum Development, National Education Association, 1201 16th St., N.W., Washington 6, D. C., issues, usually at three-year intervals, *List of Outstanding Curricular Materials.*

Educational Index, under subject area, lists some recent courses of study.

School Life of the U. S. Office of Education occasionally lists new curricular materials and courses of study.

The National Science Teachers Association, 1201 16th St., N.W., Washington 6, D. C, has some lists of curricular materials in science.

(b) Patterns of course structure, patterns of content, and even objectives may be elicited from a study of *textbooks, old and new.* Certainly authors of modern textbooks make careful curriculum studies before they develop their texts.

In addition, most textbooks now have an accompanying program of tests, laboratory manuals, workbooks, and teacher's manual. The teacher's manual certainly is a valuable aid to a teacher's developing his own course; laboratory manuals and workbooks are useful as sources of activities. Surely, a biology

teacher or the staff library should have many of the available biology texts.

(c) In addition, these *references* may prove useful:

Morholt, Brandwein, and Joseph, *Teaching High School Science: A Sourcebook for the Biological Sciences*, Harcourt, Brace, N. Y., 1958, contains a lengthy bibliography including biology textbooks, lists of films and filmstrips, descriptions of classroom and laboratory facilities, and descriptions of some thousand or more activities in biology.

R. Will Burnett, *Teaching Science in the Secondary Schools*, Rinehart, N. Y., 1957, see especially the section on the teaching of the topic "Race," pp. 271-92.

(d) Finally, you will wish to write to certain individuals and offices for assistance. Among these would be:

U. S. Department of Agriculture
U. S. Department of Health, Education and Welfare
State Departments of Agriculture and of Health
State Experimental Stations of Agriculture, Forestry, Fish Hatcheries
Hospitals and medical laboratories
Manufacturers of pharmaceuticals, processed foods, etc.
Universities, both public and private
Colleges in your vicinity

12-2. You may find it useful to examine the course outline in biology of five schools (preferably of schools near you). How would you classify each of them? Do they fit into the patterns described under the heading, Patterns of Present Courses?

12-3. Observe biology classes of comparable pupils in schools using quite different types of course organization. In which do the children undertake the most self-initiated study? How do these pupils perform on standard examinations? Are different types of course organization used for children of different abilities? In which type of course does the teacher seem most relaxed and happy? What variety of materials, resources, and experiences are used with each type of course design?

12-4. How do the experienced biology teachers you know treat "controversial" topics? Do those who commonly lecture deal with such topics? Specifically, inquire about evolution, human reproduction, and vivisection.

12-5. Have you noticed the variations in various high school biology textbooks' treatment of the same topic? You might want to compare them, for instance, on the basis of technical vocabulary. Can any technical terms be replaced with more commonplace (nontechnical) words? Should this be done?

CHAPTER 13

Inventions in science courses:

The course in chemistry

A note at the beginning:[1] It is still true, of course, that college entrance requirements exert a strong influence on the high school course in spite of the fact that only 20 per cent of our high school graduates enter college.[2] It is also true, however, that many colleges are accepting modified chemistry courses as an entrance requirement in lieu of the more usual college preparatory chemistry course. As a result, more and more boys and girls are enrolling in applied chemistry courses.

Note the term "applied chemistry course." Applied to what? Isn't the "college entrance" course in chemistry "applied" to some purpose? Or are these terms "college entrance chemistry" and "applied chemistry" meaningless?

For over a century chemistry has been taught in the secondary schools of this country. At present about half a million pupils, most in the eleventh grade, are enrolled in chemistry each year. Evidently the present courses are successful, or not too unsuccessful; otherwise the enrollment would not be this high. Yet chemistry in public schools enrolled in 1956 only 34.6% of the children in the eleventh grade.[3] As science teachers we are acutely aware of the importance of chemistry. Certainly we can see that chemistry should be significant to a greater fraction of the students than now elect it. What factors act to depress the enrollment? How did the courses now being offered come into existence? How might they be changed to be more attractive to the science shy, the average, and the science prone?

[1] Quotation from Bernard Jaffe, "Trends in High School Chemistry," *National Association of Secondary-School Principals Bulletin*, Jan. 1953, pp. 67-75.

[2] This percentage has been rising and is now closer to 30.

[3] K. E. Brown, *Offerings and Enrollments in Science and Mathematics in Public High Schools*, U. S. Office of Education Pamphlet No. 120, U. S. Government Printing Office, Washington, D. C., 1957. For a fuller discussion of trends in enrollment in high school science courses, see our Chapter 12, The Course in Biology, and Chapter 21, Supply and Demand in Science.

Development of the course in chemistry[4]

Chemistry in American high schools shows, like biology and physics,[5] the strong impact of early collegiate domination. In the earliest American secondary school, the Latin grammar school, no science whatever was taught. This first school was intended to prepare students to read Latin and preferably Greek also in preparation for college. Colleges then were a far cry from those of the present; their major concern was the preparation of young men for the ministry.

Later the academies, like that founded in 1750 by Benjamin Franklin, presented a more varied and practical course of study including some science. But there was still no chemistry until the beginning of the nineteenth century. Then, when the establishment of the public high school had begun, and after Lavoisier and Priestley had furnished chemistry with its first important concepts and procedures, chemistry gradually appeared in the American high school. For the most part this earliest chemistry, like botany and zoology, was taught catechistically as a series of teacher-questions and student-answers enlivened with dramatic demonstrations: the volcano, and assorted odors. In the early 1800's chemistry was considered (for some reason) a science most fit for young ladies, and many of the "female academies" advertised "a good chemical apparatus." Others foresaw the industrial and agricultural importance of chemistry and urged its teaching as a means of avoiding the necessity of importing chemicals from Europe. But generally there was no central purpose to the new course either in the colleges or in the high schools.

During and after the Civil War chemistry became more popular, and laboratory work for both boys and girls was stressed. In part, this stemmed from the wide acceptance of Froebel's emphasis upon work with the hands as a form of creative expression, and in part, from the success of the chemical theory of Avogadro as clarified by Cannizzaro in 1859. Now there was something to teach and a way of going about teaching it. Seemingly with more enthusiasm than wisdom, the "discovery method," or heuristic approach, was hailed as the key to all science teaching. By learning how to discover in science, students would be able not only to observe better, but to do better. In chemistry, as in the other sciences, laboratory work was the panacea, and unattainable objectives were propounded.

In keeping with the spirit of the times, Harvard College in 1886 added "laboratory chemistry" to the courses on its admissions list for students seeking advanced standing. To provide guidance to schools offering such a course, Professor Josiah Cooke of Harvard prepared a list of 85 experiments, later reduced to 60, in qualitative and quantitative chemistry. Students were expected to perform most of these in school and were individually tested in the laboratory

[4] This section is based in part on: S. Rosen, "The Rise of High School Chemistry in America (to 1920)," *Journal of Chemical Education, 33,* 627, 1957, and "A History of Science Teaching in the American Public High Schools, 1820-1920," unpublished Ph.D. thesis, Harvard U., Cambridge, 1955.

[5] See Chapters 12 and 14.

when they came to Cambridge to apply for admission to the college. This list of experiments was soon known as "The Pamphlet" and went through several revisions as the result of criticisms and school experience.

Cooke's "Pamphlet" focused attention on the purpose of chemistry in the schools. Many hailed it, texts were soon written to conform to the plan. Others, however, bitterly complained that it was too difficult, too quantitative, too deficient in descriptive and qualitative chemistry, too mathematical, and too theoretical. Actually, this course was too advanced and abstract for many of the pupils. A few, but far from all, other colleges followed Harvard in accepting a course of this type for advanced standing.

In the *Report of the Committee of Ten on the Reorganization of Secondary School Studies* in 1894,[6] the recommendation was that chemistry be accepted for admission to all colleges. This recommendation was not rapidly accepted; relatively few colleges would accept chemistry as a course for admission until some years later. Harvard in 1900, Yale in 1911.

In 1902 Alexander Smith[7] found that chemistry courses fell into three major types:

1. The discovery or heuristic, with strong emphasis upon laboratory work.
2. The theoretical, which dealt with the gas laws, atomic theory, and Avogadro's hypothesis.
3. The historic systematic, which dealt with oxygen, hydrogen, water, etc.

Although collegiate emphasis was upon the second form, the prevailing form practiced in secondary schools was the third. Ten years later, in 1912, textbooks were found[8] to be organized around water, air, salt, and the periodic table.

Throughout this period the schism between schools and colleges had been developing. Two major factors were working. First, the rapid expansion of secondary schools had produced a quantitative demand for teachers far in excess of the number of able new teachers available; as a result many classroom teachers were themselves unable to handle effectively the details recommended by the colleges. Second, and perhaps more important, was the expansion and change in the student body within the schools. Teachers realized that they were expected, under compulsory education laws and general public enthusiasm, to educate *all* American boys and girls. With a heterogeneous student body having diverse interests and abilities, the rigid high school chemistry course proposed by Cooke was no longer suitable; for many of these boys and girls were not certain of completing high school, or were not necessarily going to any college, or found the chemistry course too difficult or uninteresting, or were not mentally equipped to master the many principles, facts, and quantitative aspects of the existing course.

In retrospect the initial college domination appears to have had consider-

[6] American Book, N. Y., 1894.

[7] Alexander Smith and E. H. Hall, *The Teaching of Chemistry and Physics in the Secondary School*, Longmans, Green, N. Y., 1902, p. 19.

[8] S. Rosen, *A History of Science Teaching*. . . ,

able value. Chemistry was moved into a position of academic respectability. New, if unrealistic, standards of performance and teacher competence were defined. Yet, as the high schools passed from college preparatory to common schools, changes were difficult and the definition of a new center of concern—a basis for more effective courses—was not sharply defined or made operative. The struggle to reorient chemistry has been a long evolutionary one. It continues, with vestiges of almost every earlier course plan still in use.

Numerous attempts have been made to reorient and redesign the course in chemistry. One has been to use the basic ideas of the college-preparatory course as a frame with changes in sequence and emphasis. The knowledge of elements, compounds and mixtures, physical and chemical changes, water and solutions, acids, bases, and salts, as well as some typical fundamental chemical reactions, was used as the basis upon which other optional topics were developed.

Another attempt was to explore the ways in which the materials of chemistry could be used to further general education, the content which would be most appropriate, and the methods which would be most feasible. In 1947 the Committee for the Study of Science Education commented: [9]

> The secondary school course has usefulness for the purposes of general education. . . . Accordingly, chemistry teaching should clarify the relation of chemistry to health, to vocational pursuits, and to the other aspects of living to which the subject matter of chemistry relates and to which it can contribute understanding.

Not only the purposes and methods, but also the organization of chemistry courses have come under scrutiny. We quote again from Jaffe: [10]

> Organization of topics in a chemistry course has also undergone some modification. The popularity of textbooks which divided the course into *tight* units is waning. The effect of this artificial grouping of chemical knowledge resulted in mental indigestion for the pupil and in a strait jacket for the inexperienced or beginning teacher. . . . The [tight] unit treatment seemed logical enough but created difficult learning situations. Today, the trend in organization of subject matter follows the psychological order. Difficult concepts and hurdles are carefully interspersed throughout the course so that understanding is not permitted to tail-spin or interest to fall too sharply.

Patterns of present courses in chemistry

The college-preparatory course

How well does success in the college-preparatory course in the high school enable us to predict future success in college chemistry? The answer is "very poorly." About all we can say is that a student who has difficulty with high

[9] National Society for the Study of Education, *Forty-Sixth Yearbook*, Part I, *Science Education in American Schools*, U. of Chicago Press, Chicago, 1947, p. 199.
[10] B. Jaffe, *op. cit.*, p. 71.

TABLE 13-1 College-preparatory courses in chemistry *

High school (West)	*High school (East)*
History of chemistry	Introduction
Oxygen	Solutions and water
Hydrogen	Oxygen and hydrogen
Atomic theory	Atomic structure
Formulas and equations	Chemical nomenclature, formulas, equations, *and problems*
Sodium	Periodic table, metals, nonmetals, and inert elements
Sodium compounds	The halogens and their compounds
Chlorine	Sodium and calcium compounds
Problems (Avogadro's hypothesis)	*Ionization*
Sulfur	Sulfur and its compounds
Ionization	Nitrogen and its compounds
Reactions—reversible and nonreversible	Carbon and its oxides
Nitrogen	Nuclear energy
Halogens	*Organic chemistry*
Carbon	Metallurgy
Calcium and its compounds	Principles of reaction
Metals	
Important mineral substances	
Activity of metals, electrochemical series	
Compounds of carbon	

High school (Midwest)	*College text*
Oxygen	The background of chemistry
Hydrogen	Measurements and methods
Water	The commonest element: oxygen
The structure of water	Another gaseous element: hydrogen
Formulas and equations	The nature of gases
Chemical calculations	Concerning atoms and molecules
Acids, bases, and salts	The two compounds of hydrogen and oxygen
The halogens	The atmosphere and its constituents
Sodium, potassium, and compounds	The particles atoms are made of
Sulfur	The structure of atoms
Nitrogen *(The atmosphere)*	The formation of compounds
Carbon and compounds	The release of energy
Fuels	The nature of the solid state
Calcium and its compounds	Solutions, their nature, properties, and laws
Metals	Some important complex ions
Iron and steel	Reactions depending on the mobility of electrons and of protons
Copper, zinc, tin, and lead	Speed and balance in chemical reactions
Aluminum and magnesium	The extremes of the periodic system
Mercury, silver, and other metals	Chemicals from salt and sea water
Colloids	Sulfur: base of modern industry
Organic chemistry	Phosphorus and fertilizers
Textiles, dyes, and plastics	Metallurgy: iron and aluminum
Foods, drugs, and cosmetics	Magnesium and calcium; hard water
Nuclear chemistry	Carbon and silicon, glass and ceramics
	A bit about organic chemistry
	The rest of the periodic system

* Note that many college courses do not follow this pattern, nor do all the college textbooks; see, for example, L. Pauling, *General Chemistry*, 2nd ed., W. H. Freeman & Co., San Francisco, 1953.

school chemistry will have little chance of success in the college course. Even outstanding success in secondary school chemistry is no guarantee of collegiate success. The theory studied in high school is necessarily elementary; that in college is considerably deeper. The college course also begins to stress mathematical treatment, which may overwhelm the student who needed little more than a good memory and simple arithmetic for success in the high school course.

Despite all the reports and studies, the present high school college-preparatory course is markedly similar to that of the 1920's.[11] One need only compare the chemistry syllabuses of New York State, which have influenced those of many other states, in the 1920's with the revisions of 1938 and 1956 to note how much of the fundamental framework remains intact. The syllabuses have been expanded (rather than revised) through the inclusion of recent developments which require greater time and attention than did the few materials deleted. Teachers' complaints are frequently heard; increasingly their courses become a race against the clock, and lectures must be used to "cover" the material.

Table 13-1 shows three typical college-preparatory syllabuses and the outline of a widely used college text. Compare them for details and organization. Also, if practical, compare them with similar syllabuses from twenty or thirty years ago.

The principles course

While chemistry and all other sciences abound with principles, it does not follow that a chemistry course is necessarily a "principles course." This will depend largely on the content selected and the methodology used to teach it. While newer statements of aims and objectives are putting more emphasis on principles, too often in chemistry the principles are taught as isolated items not applied or developed through further work (e.g., the laws of definite and multiple proportion). Also, the interrelation among principles frequently is not established (e.g., the principle "reactions go to completion" is not applied in the study of industrial processes and the use of catalysts). Usually principles seem to be derived from the topically organized course illustrated in Table 13-1.

A different course in chemistry

As in other areas in science, there is a cutting edge, a point at which advanced thinking about the course of study, as well as experimentation, is taking place in the teaching of chemistry.

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[11] For various statements see the following in the *Journal of Chemical Education*: "Report of the New England Assn. of Chemistry Teachers' Committee on College Entrance Examinations," *16*, 46, 1939.
"The Chemistry Examination of the CEEB," John T. Tate, *17*, 443, 1940, and *18*, 441, 1941.
"A Minimum Syllabus for a College-Preparatory Course in Chemistry," John C. Hogg, *27*, 46, 1950, and M. M. Whitten, *34*, 307, 1957.

TABLE 13-2 *Proposed course outline for high school chemistry based on chemical bonds as the central theme* *

I. Introduction
  A. Metric system

II. Elements and Atoms
  A. Laws of chemical combination
  B. Atomic weights and symbols
  C. Atomic structure
    1. Electrons
    2. Electronic forces coulombic, exchange
    3. Atomic numbers protons and neutrons
    4. Periodic table

III. Chemical Bonds—Discontinuity of Chemical Change
  A. Bond types ionic, covalent, metallic
  B. Physical properties of substances
    1. Gases
      a. Gas laws
      b. Kinetic molecular theory
    2. Liquids
    3. Solids
      a. Crystals, e.g., diamond, sugar, sodium chloride
  C. Physical transformation and temperature
    1. Gas to liquid
    2. Liquid to solid
    3. Relation of mass to properties
    4. Relation of transformations to bond types
    5. Classification of matter and physical transformations
      a. Mixtures
      b. Solutions
      c. Compounds
      d. Elements
    6. Purification procedures
  D. Discontinuities between elements and compounds

IV. Chemical Change and Covalent Chemical Bonds
  A. Reactive systems go to unreactive systems
    1. Inert gases
    2. Reactivity and structure
  B. Methane, hydrogen, chlorine, hydrogen chloride
    1. Physical properties
    2. Substitution reactions
      a. Formulas
      b. Equations
      c. Calculations
    3. Chloromethanes
  C. Oxygen, water, and carbon dioxide
    1. Combustion
    2. Chemical energy
  D. Chemical geometry

V. Chemical Change; Metallic and Ionic Bonds
  A. Atomic structure of metals
  B. Oxidation and reduction (metals plus nonmetals yield ions)
  C. NaCl, $MgCl_2$, KCl, MgO
    1. Physical properties
    2. Simple chemistry
  D. Electrolysis to produce Na, Cl_2, Mg
    1. Main chemistry of electrolysis

VI. Periodic Table

VII. Hydrogen, Chlorine, Hydrogen Chloride
  A. Relative attraction for electrons, e.g., stabilities of NaH, NaCl, and HCl
  B. Polar covalent bonds
  C. Properties of HCl

VIII. Properties of H_2O
  A. Physical properties
  B. Reaction with HCl
  C. Reaction with Na

IX. Acids and Bases
  A. Stoichiometry
  B. Titration

X. Nitrogen and NH_3 System
  A. Equilibrium

XI. Polyatomic Ions
  A. Oxidation of NH_3 to yield NO_3^-
  B. Sulfuric acid

XII. Bonds Between Like Atoms
  A. Carbon chains
  B. Multiple bonds
  C. Functional groups

* Strong and Wilson, "Chemical Bonds . . . ."

One such course, a very interesting one, is described here:[12]

In much that has been written in recent years concerning the effective relationships between high school and college chemistry courses,* two comments recur: (1) care should be taken to avoid wasteful repetition between the two courses, and (2) performance in freshman college chemistry appears to be little influenced by whether or not the student has had high school chemistry. This latter statement seems to imply that the standard high school chemistry course is ineffective as a basis for more advanced work. Furthermore, it borders on a gratuitous insult in the face of the fact that most college chemistry students say they found their original interest in chemistry during their years in high school. . . .

At a conference sponsored by the Division of Chemical Education of the American Chemical Society and the Crown-Zellerbach Foundation held at Reed College, Portland, Oregon, in June, 1957, a group of high school and college teachers again discussed the integration of high school and college courses. It was agreed that repetition is a most useful aid in learning. The problem is one of judgment as to the material to be included at each level. The group at Reed College did not arrive at an answer to this problem, but one proposal emerged from the discussions which offers a way to move forward. It was agreed that a good high school chemistry course ought to have a quality of intellectual integrity that can be communicated to the student, and that this could be achieved by having a focus toward which most of the discussion could be directed. If a course for high school students could be devised with a central theme less broad than the whole of chemistry, but including the major paths by which a chemist proceeds in his dealings with chemical phenomena, then it ought to be possible to produce a reasoned argument for the topics to be included or excluded, the order of presentation, and the points at which individual variation might most readily be introduced.

A major differentiating aspect between chemistry and other branches of natural philosophy is the concept of chemical bonds. Indeed, the making and breaking of these ties between atoms is chemistry. Our proposal is that "Chemical Bonds" is the logical central theme† for a meaningful high school course. It is a theme large enough to include a great amount of descriptive chemistry and at the same time to serve as a guide to the items which can best be included in the course itself [see Table 13 2].

* See, for example, L. B. Clapp, "Reducing Duplication in High School and First-year College Chemistry," *J. Chem. Educ.*, *32*, 141, 1955.

† W. Huckel, *Structural Chemistry of Inorganic Compounds*, Vol. 1, Elsevier Publishing Co., Inc., Amsterdam, 1950, p. 44.

The applied chemistry course

Compulsory education has brought to the high school a considerable number of students who are nonacademically minded. At best, the high school course will be terminal for these students; from their ranks come the many who will drop out of school before graduation. These pupils are not equipped to handle the more demanding features of the typical (college-preparatory) high school chemistry course.

The course in applied chemistry was designed to present these students with a knowledge of chemistry that would achieve some of the broader objec-

[12] Laurence E. Strong and M. Kent Wilson, "Chemical Bonds: A Central Theme for High School Chemistry," *Journal of Chemical Education*, *35*, 56, 1958.

TABLE 13-3 A syllabus in applied chemistry *

First Term, Class as a whole	Second Term, Reorganization into optional groups
I The work of the chemist	OPTIONAL GROUP A
II Nature of matter	I. Fuels and combustion
III Solution	II. Metals
IV Water	III. Alloys
V Electrical nature of matter	IV. Conservation of natural resources
VI Formulas and equation writing	OPTIONAL GROUP B
VII. Chemical arithmetic	I. Textiles
VIII. Acids, bases, and salts	II. Dyeing
	III. Cleaning
	OPTIONAL GROUP C
	I. Drugs
	II Cosmetics
	III. Insecticides and repellents
	IV. Photography

* Applied Chemistry for High School Students, Curriculum Bulletin No 2, Board of Education, City of New York, 1948 49 Series.

tives of general education (p. 214). Typically, such courses devote about one half to two-thirds of a semester to "basic" chemistry (from the concept of elements, compounds, and mixtures to a study of acids, bases, and salts) Abstract topics such as atomic structure or chemical shorthand are treated lightly, in keeping with the students' inability to digest material of this nature. The groundwork having been laid, the balance of the year is devoted to a study of broad topics of industrial applications, such as fire and fuels, textiles, dyes and bleaches, household cleaning materials, materials of construction, and drugs and cosmetics. An example of a syllabus of this nature is shown in Table 13-3.

The functional course

While dyes, cosmetics, bleaches, and so forth, are important applications of chemistry, we are naive to assume that the student inevitably has a burning interest in them. Those who defend the inclusion of such materials in a course cannot escape the fact that whatever reasons we advance for the importance of these materials are teachers' reasons. So far as the student is concerned, the reasons are tenuous After all, of what value to him is a knowledge of these materials? In what way can he see a *use* for the knowledge? How do they relate the student to his environment, both local and national, in a significant manner? How will this knowledge influence his later behavior?

Some school systems have striven toward a course designed to emphasize the values of chemistry to the student as an individual, a member of the community, and a member of the nation. Such courses, designed to answer the questions above, are usually called "functional courses," a typical study of

TABLE 13-4 A course in functional chemistry (Denver) *

The introductory units (12 weeks) †

I. Why study chemistry

II. Importance of chemistry in modern life

III. The fundamentals of chemistry

The functional units (26 weeks) ‡

IV. Chemistry of the individual
   A. The chemistry of water in the body
   B. The chemistry of food within the body
   C. The interdependence of plant and animal life
   D. The chemistry of glands of internal secretion
   E. The chemistry of bacteria and disease
   F. The chemistry of drugs and medicines
   G. The chemistry of clothing
   H. The chemistry of cosmetics
   I. Chemical hobbies
   J. Vocations related to chemistry

V. Chemistry of the home
   A. Chemistry of cooking
   B. Chemistry of cooking utensils
   C. Chemistry of tableware
   D. Chemistry of fuels
   E. Chemistry of refrigeration
   F. Chemistry of sanitation
   G. Medical services in the home
   H. Chemistry of construction and construction materials
   I. Chemistry of paints, varnishes, and lacquers
   J. Chemistry involved in landscaping and gardening

VI. Chemistry of the community and the nation
   A. Chemistry of water purification
   B. Chemistry of the manufacture and distribution of foods
   C. Chemistry of sewage disposal
   D. Chemistry of purification of air
   E. Chemistry of industries

* Maurice Ahrens, Norris Bush, and Ray Easley, in *Science in General Education*, ed. by V. T. Thayer et al., Commission on Secondary School Curriculum, Progressive Education Association, D. Appleton Century, N. Y., 1938, pp. 465-75. This outline served as the basis for the text *Living Chemistry* (and its laboratory manual) published by Ginn.

† These three introductory units are devoted to the minimum of the fundamentals of chemistry needed for the functional units: matter, energy, structure of matter, formulas, oxygen and hydrogen (very brief), solutions and ionization, equations, acids, bases, salts.

‡ Each of these lists of problems is not considered completely in each class, and no student studies all the problems taken up within the class group.

which is presented in Table 13-4. These courses attempt to get closer to the student's "needs and interests." [15]

The honor course

The changing high school population focused our attention on the problems of the nonacademically minded pupil. As is often typical in human relations, the good and superior students were "taken for granted." After all, they posed no obvious problems and were hence left to themselves. But the long-time result has been one of neglect; their talents were left unconsidered and unexplored. In recent years, it has been more usual to hear the question, "What are we doing for our brighter students?" Many schemes in answer to this question have to do with newer administrative procedures in the school as a whole, by way of honor classes and honor schools within a school. Where numbers permit, as in large cities, special schools may be set up for the talented with admission being by examination only. For chemistry in particular, there has

[15] For brief descriptions of other courses of this type, see V. Eaton and S. R. Powers, *New Directions in Science Teaching*, McGraw-Hill, N. Y., 1949.

developed the scheme of providing an advanced course for the brighter students. This is equivalent to first year college chemistry. (The topics and treatment are those of a freshman course; a college text is employed.)

The pendulum seems to have come full cycle after almost a century. The early Harvard proposals, which affected chemistry teaching for almost half a century, prescribed a course which enabled the student to enter college with advanced standing in chemistry. There is an important distinction, though. this course was then given to *all* students; today we do the same thing, but *only with those select few* who are capable of, and interested in, such an undertaking.

Frames for developing a course in chemistry

Objectives as a frame of reference

In 1925 Powers[14] summarized the objectives of high school chemistry teaching stated in many sources. The list was too long to be covered adequately within one year. Some of the objectives bowed to the "disciplinary value" of chemistry, while others were vague and without meaning. A committee writing later on this situation for the *Thirty First Yearbook* of the NSSE reduced this long list to a few broad objectives:[15]

> 1. Pupils in high school chemistry courses should develop better understandings of those fundamental concepts, major ideas, laws, or principles of chemistry that will enable them better to interpret natural phenomena, common applications of chemical principles, and industrial applications and uses of the principles of chemistry
>
> 2. Pupils in high school chemistry classes should learn to use the processes of reflective thinking, problem solving, and techniques of study that are best adapted to the solution of problems within the field of chemistry, especially those which most often present themselves in daily life.
>
> 3. Pupils in chemistry . . . should develop those attitudes toward the facts and principles of chemistry and toward the methods of investigation employed in the field [of chemistry] that will serve as guides in their use of chemical facts and principles and methods of problem solving.

These objectives are essentially of, by, and for chemistry, they are rooted in chemistry as a subject distinct from other sciences and from life in general. They look to the results of the course in chemistry as being applicable only to chemical situations. These objectives, stated in 1932, seem too narrow today. Yet an examination of textbooks and courses of study will indicate that they are still being used widely.

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[14] S. R. Powers, *A Diagnostic Study of the Subject Matter of High School Chemistry*, Contributions to Education, No 149, Bureau of Publications, Teachers College, Columbia U., N. Y., 1924, also, "Achievement in High School Chemistry—An Examination of Subject Matter," *School Science and Mathematics*, 25, 52, 1925.

[15] National Society for the Study of Education, *Thirty-First Yearbook*, Part 1, *A Program for Science Teaching*, U. of Chicago Press, Chicago, 1932, p. 259.

But chemistry taught in the high school is clearly a part of general education, and it has significance for all. If students are asked to name something in the home or among their clothes, or a medicine, which the chemist has not improved, they will have difficulties. Clearly chemistry has relevance to our life and living. Just as clearly the chemistry course in intent and content could provide a new insight into our modern civilization and into the impact science has upon how we live and what we live with. Pertinent objectives are those which students see as part of their lives, which were stated in Chapter 5. Why are these so rarely operating in classrooms?

Like many significant questions, this is easier asked than answered. Yet several separate factors are probably working. Often the teacher is not sure what his intent really is. Is he a chemist teaching? How can he resolve his interest in the subject area and the advice of distinguished chemists with the realities of the pupils in his classes? To what extent can he escape this dilemma by throwing the responsibility upon some examination for which he must "prepare" the students? Here we squarely encounter the conflict which arose in the early decades of the century. If we were obliged to "take a stand," we would prefer a teacher who thoroughly knows his subject but whose allegiance is to the students. He can use his knowledge to help them learn, as we shall see.

In comments upon this failure of science teachers to accept and apply the objectives of general education, the Harvard Report states: [16]

> The teacher is not always clear whether he is engaged in special or general education, what proportion of his effort is to be spent on coverage and in being factually up-to-date, to what degree he is training for manipulative skill, and so on. From the point of view of general education, we are interested in these things not primarily for their own sake, but as they fit into an integrated intellectual structure. Science instruction in general education should be characterized by broad integrative elements—the comparison of science with other modes of thought, the comparison and contrast of the individual sciences with each other, the relation of science with its own past and with general human history, and of science with the problems of human society. These are the areas in which science can make a lasting contribution to the general education of all students. Unfortunately, these areas are slighted most often in modern teaching . . . because the teacher is engaged in continuous struggle to encompass the subject matter. How is he, then, to deal with extra things—the critical examination, history, literature, and general cultural content of his subject? It is of course true that as *extra* things these aspects of scientific instruction should be impossible. *But they are not extra things—they are the very stuff of science in general education.* Once it is clear that he is engaged in general rather than special education, these are the things which must be emphasized, and to an increasing degree as the student matures. . . . The *integrative element* is the student's own mode of life and his personal relation to the immediate environment.

Conceptual schemes as a frame of reference

Objectives alone do not underpin a course. A course has its framework in conceptual schemes as well. Chemistry, like all courses with a bona fide area of development, has concepts and principles which are peculiar to it. To mention a few

The behavior of chemical elements can be predicted from a knowledge of atomic structure.

Atomic structure provides an arrangement of the elements which shows them to exist in families rather than as individual elements.

Chemical changes follow quantitative laws.

It is thus possible, if one wishes, to organize the course on the basis of broad conceptual schemes such as these.

Needs and interests as a frame of reference

Anyone who has taken a course in chemistry knows how its study could fulfill certain needs and interests of young people. Here are some "problems" which relate directly to students' lives and will involve the normal content of the chemistry course in a way significant to students:

1. How can we avoid the danger of spontaneous combustion in the home? (Expand further to deal with methods of fighting the possible types of fire in the home.)
2. What typical household chemicals may be dangerous to use? (We shall certainly cover a multitude of facts in answering this problem.)
3. What may be done at home to soften "hard" water?
4. How can we assure a safe water supply?
5. How can chemistry help us in the disposal of waste?
6. How can useful materials be obtained from farm waste?
7. How can chemistry provide for our needs for metals in the face of shrinking ore deposits?
8. How does chemistry help in improving our health? Our food supply?

Note that even these few problems relate the student to his home, his community, his nation, and his environment.

But these "needs and interests" may seem subject-centered rather than needs centered Somehow "needs centered" involves rather personal choices. In a chemistry course in which one of us taught, the students chose as a central problem "The Analysis of Body Tissue." For the first half of the term, students planned to examine certain of the tissues, particularly blood, under the microscope. Then, using various texts in biochemistry as reference, they analyzed blood for its various constituents, using gravimetric and volumetric methods

The students were enjoying the course hugely (it had been going on for a month and a half) when one student, more concerned with the facts of life than

with the facts of biochemistry, asked, "Does this course prepare us for college entrance examinations and the Regents Examination?"[17] The answer was, of course, "Not if it's a typical examination." To this answer students responded variously, but there was quite a bit of concern. The problem was solved, courageously, in this way.

Students and teacher agreed that even though it was not possible to orient this course toward the examination, some preparation for the examination was still desirable. They agreed that in analyzing blood, they had learned the language and tools of chemistry. For instance, they had learned to write formulas, do quantitative problems, make solutions of the desired strength, and so forth. They further agreed that even with the best of intentions the entire standard course could not be covered. Hence, this plan was worked out:

1. Students studied past examinations. They worked out a plan of reading which would enable them to "cover" the necessary material. One day a week was spent in quizzing each other (with the teacher's help) on standard formulas, equations, preparations, and so forth. When a standard demonstration to illustrate the material under study was required, it was done by students or the teacher.
2. Meanwhile, they continued their work in biochemistry, and then went into organic chemistry (particularly esterification).

The students were successful in the state Regents Examination. As far as could be determined, students in this course did as well as other students of equal I.Q., reading score, and mathematics score who took the standard course. This no longer surprises us, although it did at first. Students who are vitally interested generally read more, do more, and learn more.

Note again that planning with students does not result in lowering "standards," but results actually in increasing the vigorous application of the students. The teacher does not abdicate; he remains a teacher. This means raising the standard; this means that students work harder and learn more.

But what if a student had *not* asked, "Does this course prepare us for the college entrance and the Regents examinations?"? In our experience, in years of planning with students (in classes where there are boys and girls who plan to go to college), this question has *always* been asked. Where there is an absence of threat, students do ask sensible questions and arrive at sensible answers—with the help of the teacher, of course. The teacher, we repeat, does not abdicate; he is *the* guide to learning. When he is such a guide, more subject matter is learned than when he is prescriptive; such is our experience.

And what of special personal interests? Crystallography? Crime detection? To learn firsthand how chemistry is used in the detection of crime, a student must become acquainted with a considerable body of facts about chemical

[17] Regents Examinations are the state-wide examinations of the Board of Regents of New York State; they reflect the state syllabus.

analysis. If he is attracted by the interesting possibilities of electroplating or wants to know how a plastic is synthesized, he will soon be acquiring much specialized information on his own initiative, and judging the significance of this information as it applies to his problem. He will be practicing the art of the scientist.

In another school, a student asked during the first week what was left after the oxygen had been evolved from $KClO_3$. It "should" be KCl, but was it? The student was encouraged to find out, and over the next weeks was involved in techniques and learnings which "normally" came later in the course. Because he wanted to answer a question, he willingly learned much that is generally considered difficult. Since not every student will be interested in the same topic, such projects provide for individual interests. They can be carried out during, before, or after class, either at home or at school.

Units as a frame of reference

More than any other device, the unit has been used as a base for organization of the chemistry course. Clearly units can be organized around conceptual schemes, problems, needs and interests, or utility in our society. In chemistry, units have been organized in topics (oxygen), conceptual schemes (periodic table), or fields (metallurgy). There seems to be no rhyme, if indeed there be reason, for this organization.

For instance, a unit on metallurgy may be based not on a single conceptual scheme or a "need and interest" or even a problem, but on the utility of metals in our society. Nevertheless, in terms of the task of maintaining the student's interest, a unit on metallurgy which stresses the general principles in obtaining, using, and protecting all metals clearly surpasses the disjointed treatment in which the metals are given individual study, each isolated in its chapter.

Whether or not the frame of reference is in conceptual schemes or personal interests, the basic organization necessarily includes a large body of

TABLE 13-5 ***A course based on large understandings*** *

I. Chemistry in the present world—introductory
II. A chemical view of matter
III. Some common chemical elements—common structure
IV. The world of water and solutions
V. Important classes of chemical compounds
VI. The families of elements
   A. The halogens
   B. Sulfur
   C. Nitrogen, including the atmosphere
VII. Chemical theories and their applications
VIII. The world of metals
IX. Carbon and its compounds
   A. The oxides
   B. Petroleum chemistry
   C. Organic chemistry

* In each unit the necessary skills (writing formulas and equations, problems, etc.) are taught.

subject matter, the mastery of which results in understanding of some large *principle or function*. Usually (as will be seen in Chapter 17, The Unit in the Course), the sequence of units is planned to proceed from less difficult principles to those of greater difficulty. Usually, skills and attitudes are stressed in relation to principles and problems. Nevertheless, the units of a chemistry course often do not have a parallel construction.

Table 13-5 is an example of one course in which the units do have parallel structure based on large understandings or functions.

Special considerations in teaching chemistry

The flavor of the course

Chemistry, like each of the sciences, has its distinctive flavor. A visitor to a chemistry classroom or laboratory will likely find the teacher or students—

Decomposing an oxide.
Preparing a gas: hydrogen, oxygen, bromine.
Purifying water.
Discovering equivalent weights, e.g., of magnesium.
Finding the weight of 22.4 liters of oxygen.
Neutralizing acids and bases.
Preparing ammonia, nitric acid, hydrogen sulfide, sulfuric acid.
Studying destructive distillation.
Preparing an ester.
Determining an "unknown."

These operations and many others are the essence of chemistry. Also involved are—

A certain kind of mathematics.
A shorthand.
An extensive technical vocabulary.
Skills in designing apparatus and in manipulating equipment.

These create the odors and colors, the "feel" of chemistry; they belong to it and to no other study. Because there is so much to *do* in chemistry, it can be great fun.

Chemistry and social problems

Because chemists have been so successful in understanding and maneuvering the components of the physical world, many fundamental changes in the social domain result. Probably these are not "controversial issues," as some applications of biology are considered, but they are social problems resulting from chemistry which must be solved in part with the relevant knowledge of chemistry. Among many are these:

1. Man has learned how to transmute the elements and release enormous energies. What shall we do with this new skill?

2. Nuclear experimentation and power plants are already putting into the air disturbing amounts of radioactive materials which "fall out." How shall we deal with this? How significant are the amounts already in the air? What are the political and social implications, on a world-wide scale, of this "fall-out"?

3. The mineral resources of the world are finite and unevenly distributed. In the United States live less than one tenth of the world's population on less than one-fifteenth of the land mass. Yet we use one-half of the world's mineral resources, iron, aluminum, oil, rubber, and so forth. What are the consequences and responsibilities of this rapid use? What problems does this pose for the near future? For certain necessary materials we are a "have-not" nation (wolfram, manganese, etc.). What consequences does this have on international relations? What is the likelihood of substitutes being found?

4. We are using fossil fuels, coal and especially oil, at a terrific rate. Yet the demands for power rise continually. How will these be met? Who will make the decisions and finance the operations?

5 By 1970 our national population will be close to 200,000,000. Water is already in short supply in some areas, in part because it is used so extensively in manufacturing processes. Food for our people and possibly for the exploding populations elsewhere in the world must be grown on the same limited and well used land areas. What can be done, by whom, and at what cost to supply more water and food?

Are questions such as those above properly a part of the chemistry course? We believe they are, if we wish to have future citizens who comprehend the significance of chemistry in the world today. Yet they may be "sidestepped" in a teacher dominated course limited to "chemists' chemistry" and the "ivory laboratory." Such limitation will provide more time for technical details, but the only knowledge of the social implications of chemistry that the student will have is the haphazard knowledge he would have picked up had he not taken the chemistry course.

The problem of safety

Safety in the laboratory, where acids, bases, poisonous materials, glassware, flames, and high and low pressures are necessarily used continuously, depends upon both knowledge and attitudes. Certainly the student needs to know what materials are hazardous and what to do if an accident occurs. But knowledge is not enough. In many chemistry laboratories we have seen, the attitude of the students was far too casual They were only "messing around," usually to "prove" some result they already knew and did not care about anyway. More careful work will result as soon as the student *wants* his own

answer, and a good one, to his question. Then he will be tidy and precise. An approach which involves predictions from knowledge will identify the dangerous materials and reactions; e.g., will this reaction be strongly exothermic? If so, what would you expect to occur? What precautions should you take? This will also reduce the chances that students will, as happens too often, "pour things together to see what will happen" and have a ghastly accident. Certainly there is no single answer to this difficult question, but the attitude and approach of the instructor can make a significant effect upon the atmosphere of experimentation.

Theory vs. application in chemistry

From the beginning of the century the relative attention to theory, application, and descriptive chemistry has been argued. No over-all answer can be created, for the intent of the teacher and pupils will vary among schools. Yet chemistry is a science, which means that the multitude of specific reactions can be organized and explained through a relatively few generalizations. In some instances, a "law of behavior" can be formulated directly from the observations. In other cases, some postulated property of atoms or molecules (valence, electric charge, binding energy, elastic collisions) must be introduced as an intermediary in reaching an explanation. The success of chemistry in predicting what will occur results from these generalizations. To omit most of them for purely descriptive chemistry or for extensive discussion of the wonders of modern technology prevents the student from comprehending the significance of the descriptive information and the basis on which technologies, with multimillion dollar investments, can be created.

Historical sequence in chemistry

Every science has a long and distinguished history. This is the story of how we have the knowledge now available. A course in chemistry which uses the historical approach would begin with the Greeks. But for a course in chemistry reflecting its use in the modern world, we would accept the concept of atoms as a starting point; surely the idea of atoms will not be a novelty to the students. Then gradually questions arise about how we know when we can rely upon the existing generalizations. This is the time to repeat, perhaps, in the modern context, the classical investigations of the past (history) upon which our current knowledge rests. That is, the student needs to be aware of "how he knows" and "how well he knows." At appropriate times the struggles, achievements, and disappointments of former chemists can be used through brief case histories.[18] The purpose of this is not to teach the history of chem-

[18] Leo Klopfer and F. G. Watson, "The use of case histories in science teaching," in *Science Teaching Through Problem Solving*, Nat'l Sci. Teachers Assn., 1956, mimeographed, p. 40; see also *The Science Teacher*, *24*, 264, Nov. 1957.

istry, but to use the past to illuminate the present. A student may then see how present problems are like those encountered by chemists in the past.

The value of laboratory work and demonstrations

After the heyday of enthusiasm for laboratory work, for which preposterous claims had been made, thoughtful people began to ask what effects laboratory work had upon children's learning. In part this was motivated by the "enormous expansion" of enrollments in public high schools (from 519,000 in 1900, to 2,200,000 in 1920, to 4,399,000 in 1930). The resulting strain upon building facilities, especially laboratories for individual experimentation, was severe and expenses were high. The possibilities of group laboratory work and of teacher demonstrations were explored.

During the second and third decades of this century many experiments were made to reveal the relative merits of these different procedures. At that time educational experimentation, which was just beginning, severely suffered from "faulty and inadequate experimental and statistical techniques and the lack of reliable and valid objective tests for measuring the instructional outcomes."[19]

The nature of these insufficiencies is exhibited well in one of the later and larger studies: that by Carpenter which involved over a thousand pupils in 34 classes in 23 schools in 14 states. We quote his major conclusion, supported by the data despite the primitive statistical treatment:[20]

> The results of this experiment point to the conclusion that the majority of students in high school laboratory chemistry classes, taught by the demonstration method, succeeded as well as when they performed the experiment individually, *if success is measured by instruments which measure the same abilities as are measured by these tests,* namely, specific information and ability to think in terms of chemistry

For this to have meaning we must examine the tests he gave the pupils. As he states, they heavily involved recall of information. The "ability to think in terms of chemistry" is not so evident. The test items were based on "ten introductory experiments as found in one of [the] most popular chemistry laboratory manuals: Brownlee and others, *Laboratory Exercises,* Allyn and Bacon" (edition not cited). A perusal of these test items reveals that a competent student could answer them completely on the basis of a textbook knowledge *without either* demonstration or laboratory work.[21] Little wonder then that he did not find large differences between the results of presenting the phenomena to the students in the two different ways.

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[19] NSSE, *Thirty-First Yearbook, op. cit.*, p. 97.

[20] W. W. Carpenter, *Certain Phases of the Administration of High School Chemistry,* Contributions to Education, No. 191, Bureau of Publications, Teachers College, Columbia U., N. Y., 1925, p. 45, italics added.

[21] Carpenter did not use his "control groups" (no contact at all with the phenomena) in his analysis.

Among the many studies, probably the "classic" is that by Horton.[22] Not only did he devise standard paper-and-pencil tests which required more knowledge of "doing" or "performing," but, in addition, he devised a test of laboratory manipulative skills, appraised both through written tests and direct tests in the laboratory. After extensive experimentation, he concluded: [23]

> No reliable results appear in the testing by the ordinary written examinations—neither by the Regents nor by the school test.

This is not surprising in view of the type of item and ability involved in such tests. Also he concluded: [24]

> A. The order of preference of the methods studied, in the light of all the outcomes measured, appeared to be:
>
> 1. Individual laboratory work *without directions*, the so-called "problem method."
> 2. Individual laboratory work following directions, but with these directions consciously generalized.
> 3. Individual laboratory work following directions from a manual.
> 4. Demonstrations of all experiments by the teacher.
>
> B. For success in the ordinary written test there was little preference; no method showed a superiority amounting to certainty. . . . We were left with a choice of believing that:
>
> 1. Written tests are invalid for detecting differences in methods of laboratory work.
> 2. The methods of doing laboratory work are not determining factors of success in written tests.
> 3. Both these statements may be true.
>
> [Not more than one fifth of the student's time in the course was devoted to the laboratory work.]
>
> C. There were, nevertheless, differences in the outcome of the different methods of using the laboratory. This appeared to be confirmed by all the non-written tests proposed. These differences were found in ability
>
> 1. To manipulate apparatus
> 2. To make experimentation involving use of apparatus.
> 3. To solve perplexities or projects involving use of chemical facts in laboratory situations.

He also found that 87% of the students preferred individual laboratory work to demonstrations and commented:

> From such a decisive preference for individual work we may judge that it serves at least the purpose of self-activity, motivation, and maintaining interest. On these grounds alone, the expenditure of time and money may be justified. . . . It appears that we have overemphasized individual work as a means of acquiring information and of merely understanding chemistry. On the other hand, there seem to be important outcomes from individual work measurable and attainable by suitable methods which may make it more, rather than less, important.

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[22] R. E. Horton, *Measurable Outcomes of Individual Laboratory Work in High School Chemistry*, Contributions to Education, No. 303, Bureau of Publications, Teachers College, Columbia U., N. Y., 1928.

[23] *Ibid.*, p. 84.

[24] *Ibid.*, pp. 99-102.

All this only re-emphasizes the basic question of the desired outcomes of a chemistry course Do we wish the pupils to attain primarily a static knowledge of chemical facts? If so, laboratory work, and perhaps even demonstrations, will not be essential. Tests will deal with recall of static knowledge of the type in texts. (Incidentally, enrollments will be exceedingly low.) Do we wish the pupils to see chemistry as a dynamic science, as an example of how men struggle to describe the behaviors of the world and to make sense out of them? If so, laboratory work will have a central place and will be much more than exercises repeated from a manual. The issue is just that sharp.

These questions have remained unresolved. In 1946 the committee reviewing this topic for the *Forty-Sixth Yearbook* of the National Society for the Study of Education wrote: [25]

> It is regrettable that in a majority of science classes in which demonstration and individual experiments are performed, the chief, if not the sole, function served by these activities is to verify facts and principles already learned. The experiment is commonly postponed until the pupil has found out from consulting the text or from classroom discussion what the experimental results ought to be. Then the experiments are performed so that the pupils may verify what they already know. As a result, it is common for the pupils to engage in such undesirable practices as "making the answer come out right," and telling what "ought to have happened" instead of what actually happened
>
> Performing demonstration or individual experiments merely for the purpose of verifying facts already known is rarely, if ever, justified. The primary purpose of experimenting is to secure evidence which may reveal answers to problems. In order to effect this purpose, the inductive method should be used in nearly all cases; that is, the laboratory work should precede, not follow, the classroom discussion of a topic or principle.
>
> Under this plan, the pupil needs the same careful direction for experimenting that he will require in any other case; he needs to be given, or to work out for himself with the teacher's help, the procedures to follow in securing an answer to a problem. But everything possible should be done to encourage him not to ascertain by other means what the answer should be. . . . After he has arrived at the best answer to his problem that he can reasonably be expected to obtain, it is proper for him to consult the textbooks and references to find which are the correct results, as obtained by skilled scientists working under ideal conditions
>
> Such practice is ideal for the teaching of the scientific method and for developing scientific attitudes The practice of carrying on experiments for the mere purpose of verification often emphasizes the antithesis of scientific method.

The thirteen years which elapsed should have brought a shift in emphasis in the objectives of the laboratory work in chemistry. But, to our knowledge, this shift exists in only a minority of classrooms In a great majority of chemistry classes the statement which begins this section still applies: "It is regrettable that in a majority of science classes . . . the chief, if not the sole, function served by these activities [demonstrations and individual experiments] is to verify facts and principles already learned."

This opinion was accepted as describing the present situation by chemistry teachers with whom we discussed the problem in sixteen Science Teacher Insti-

[25] *Op. cit.*, pp. 51-52.

tutes held during the summers of 1956 and 1957. It is also what we have found when discussing the situation with teachers throughout the country. In general, we find that the syllabus topics stated in Table 13-1 are used (in one sequence or another) in the majority of classrooms in this country. Similarly, we find that the topics shown in Table 13-6 constitute the laboratory exercises generally used throughout the nation—almost to the sequence.

Note that we say "laboratory exercises"; these are done by students after they have the information. Information is not gathered inductively through the experience. The laboratory experience is not in search of meaning; it is merely an exercise in laboratory manipulation, sometimes indifferently performed.

This is a most regrettable commentary about the role of laboratory work when all science teachers are aware of the central place of experimentation in science. If laboratory work is handled in the manner described just above, the abilities of children to select and design equipment, to predict from principles, to operate carefully and accurately, to observe closely, to appraise results, to search for improved techniques and equipmental design, to apply statistical analysis, to describe data graphically and algebraically, and to interpret data will not be realized. Further research on the benefits of laboratory work would normally include these attributes as central. Yet in terms of current laboratory practices, we would expect to find little or no gain in the critical scientific skills.

But basic in the current misuse of laboratory time and facilities is the clear observation that children *enjoy* laboratory work, especially when their efforts have some personal significance. A major revolution in science teaching

TABLE 13-6 Typical laboratory exercises in chemistry

1. Physical and chemical changes	23. Nitric acid
2. Elements, compounds, and mixtures	24. Oxides of nitrogen
3. Matter in chemical change	25. Sulfur
4. Decomposition of an oxide	26. Hydrogen sulfide
5. Oxygen	27. Sulfuric acid
6. Hydrogen	28. Carbon
7. Displacement of hydrogen from water	29. Destructive distillation
8. Water and solids	30. Carbon dioxide
9. Purification of water	31. Fermentation
10. Equivalent weight of magnesium	32. Esters
11. Weight of 22.4 liters of oxygen	33. Soap-making
12. Ionization	34. Foods
13. The electrolysis of an electrolyte	35. Textiles
14. *Neutralization*	36. *Relative activity of metals*
15. Reactions to completion, reversible reactions	37. Metallurgy
16. Hydrolysis	38. Qualitative analysis
17. Chlorine	39. Oxidation reduction
18. Hydrogen chloride	40. Aluminum
19. Bromine	41. Calcium, magnesium, and their compounds
20. Iodine and a fluorine compound	42. Hard water
21. Nitrogen (the atmosphere)	43. Determination of an unknown
22. Ammonia	

with a sharp rise in enrollments can be forecast if the laboratory is used in the spirit of science to inquire, to test predictions, and to wrestle with reality.

An excursion into developing one's own course in chemistry

We are forced to the conclusion that chemistry teaching, as defined by the topics taught in classroom and laboratory, is fairly standardized throughout the country. The course given is that delineated in Table 13-1; the laboratory course given is that in Table 13-6. This standardization and orientation is unlike general science and biology. What does this mean?

Perhaps this. Chemistry teachers have devised an invention which is satisfactory. It meets the needs of boys and girls, the various communities, the schools, the colleges. Furthermore, chemistry teachers are generally satisfied with this invention.

Or this: Chemistry teachers are teaching a course which fits very few young people. This might account, in part, for the relatively low enrollment in a very interesting subject.

Or this: Change in chemistry teaching is slower than in other areas. In this aspect, it is like physics teaching.

Or this: Chemistry teachers are satisfied to teach only a select group. They do not, in general, believe that all young people should have the kind of chemistry which fits their individual goals.

13-1. One teacher we know developed an entirely different course in chemistry in this way. He decided that he wanted to prepare the youngsters for that bugaboo, The College Entrance Board Examination,[28] and yet to develop a course according to what was known about modern methods of teaching, the method of intelligence, and concept formation.

This is what he did, it is similar to Mr. P.'s plan described in Chapter 4. He realized that the major obstacle to teaching in a leisurely manner a course so crammed full of facts was the lack of time. How to get time?

(a) He analyzed current textbooks and found them all very similar in content. But he also discovered that certain portions of the information need not be taught in the classroom; students could read and understand them: the history of chemistry, certain aspects of metallurgy, soap-making, etc. He did not, however, avoid *using* aspects of these topics, particularly history, to develop the way the chemist used the method of intelligence, and metallurgy and soap-making to illustrate the aspects of technology.

He therefore developed an agreement with the students. He prepared a mimeographed sheet listing the topics for which they were responsible when

[28] Taken in 1954-55 by 11,933 children out of some 480,000 enrolled in chemistry courses *Fifty fourth Annual Report of the Director*, C.E.E.B., N. Y., 1956, p. 62.

tests were given. He also listed the dates by which these topics were to be read. (These were flexible deadlines and were changed as the course developed.)

He decided that in class he would deal only with the "difficult" topics, those which had a mathematical context, dealt with laws, or dealt with conceptual schemes. All descriptive chemistry he left to the students.

(b) He allowed one period (or occasionally two) per week for clearing up difficulties which came out of the students' readings, and for performing the standard laboratory and classroom demonstrations.

(c) This left to the classroom and the laboratory such problems which developed from the very nature of chemistry, e.g.,

How do you identify an unknown ion in solution? (Much laboratory time was spent on analysis.)

How do you know that MnO_2 is a catalyst? (Experiments on catalysis were done in the laboratory.)

How do you know that weight-weight relationships really exist, e.g., in the reaction $NaCl + AgNO_3 \rightarrow AgCl + NaNO_3$? (Careful experiments were done over a period of a week.)

(d) As a test of whether his students "knew" chemistry, he used the type of test developed on p. 428, as well as various American Chemical Society tests. He found that, when taught this way, his class did as well in terms of knowledge and skill gained as they did when he was (as he put it) "bound by the rat race of the textbook and-laboratory course."

There were three most important results:

1. Those students who were going on to college did well in the College Entrance Board Examinations.

2. Those who were science shy did as well, in his opinion, as they would have done in the course he used to give.

3. The enrollment in chemistry tripled over four years.

13-2. In order to determine what is going on in chemistry courses throughout the country you might want to gather various courses of study. The approach we have found useful is described at the end of Chapter 12, The Course in Biology.

13-3. For laboratory experiments, demonstrations, field work, projects, films, etc., in chemistry you might want to examine:

J. Richardson and G. P. Cahoon, *Materials and Methods in Teaching Physical and General Science*, McGraw-Hill, N. Y., 1952.

A. Joseph, P. F. Brandwein, and E. Morholt, *Teaching High School Science: A Sourcebook for the Physical Sciences*, Harcourt, Brace, N. Y., 1959, a companion to this volume.

CHAPTER 14

Inventions in science courses:

The course in physics

A long note at the beginning: There was a teacher who gave her students an assignment, a review of a book on penguins. In order to stimulate clear thinking, as well as brevity, she asked that the review be couched in one sentence. From one boy she got this statement: "This book tells me more about penguins than I care to know."

Probably teachers of physics would say, and with justice, that they have been told more about the need for revision of physics courses than they care to know. Yet another way of putting it in one sentence would be: Physics has a tremendous impact on society, but too little impact on enrollment. This is a pity, because physics is useful, it is interesting, and it is necessary equipment for boys and girls who would understand modern society.

Why, then, do a great number of students shun the physics classroom? Let us deal only with three major myths which affect physics teaching (and for that matter chemistry teaching).

The myth of the selected student body. An examination of courses of study and methods of teaching now employed indicates that physics teachers seem to think the high school population is entirely composed of individuals with I.Q.'s of 110 or more, all interested in becoming physicists. Obviously this is not so.[1] Yet the course generally given is intended for such students. And this course seems to be even unsatisfactory for the physicist-to-be.

Most students in our schools cannot learn a vast assortment of facts unrelated to their present lives and combined with a private shorthand, a private mathematics,

[1] By definition of the I.Q. scale, just over 25 per cent of the population can score above 110.

high levels of abstraction, often symbolic, as well as the laboratory skills which comprise the existing course in physics. Enrollments in such physics courses cannot be high, because the number of students who can cope with such a course is limited. Yet the solution is clear.

1. For those who are to become experts in physics, or who are capable of this even though the interest has not yet been aroused, the course in physics as given now ought to be extended and enriched. It ought to be made, if you wish, more abstract, more esoteric, and more delightful and exciting to those whose gifts enable them to do more.

2. For those who are not to become experts in physics, a physics course suited to their needs and interests is also possible and, indeed, necessary. Such a course would deal with the problems these boys and girls will face as citizens; with topics such as the automobile, TV, electric currents, the H bomb, the bicycle, and so forth. Surely atomic energy would be dealt with in such a course, but on a level which satisfies the curiosity of such students, explains theory sufficiently for them to understand newspaper accounts, yet does not require them to write nuclear reactions and to understand fully the theory behind them.

Is this physics? Or is it watered-down physics? This leads us to the next myth which affects our thinking about the teaching of physics.

The myth of the "watered-down course." Let us make short shrift of this. If you examine collegiate physics courses, including those for graduate students, you will not find a single course (even the most advanced) which was not "watered down"; watered down, that is, from the existing body of knowledge. Every teacher selects from the body of knowledge, and every course is necessarily "watered down" or "selected" to fit the student body.

Surely it is no academic sin to fit one course to students who might be physicists or scientists (to modify a college course if need be), and also to fit a course to students who will not be physicists, by selecting materials which will help them solve the problems in physics which they will face as human beings. Or will one course do for both, a course suited to modern science and modern life?

There is all the difference in the world between teaching physics as an end in itself and teaching it as a help in solving problems of living. The first helps the experts; the second helps both the experts and those who will cooperate with them.

The myth of the physics teachers' strait jacket. Talks with many teachers indicate that they do want to introduce courses which fit both the expert-to-be and the citizen-layman-to-be: that is, they want to introduce courses to fit both special education and general education. However, they point out that courses of study set by state Boards of Education and the College Entrance Examinations are among many pressures which, they feel, restrict their flexibility. Little innovation seems present in textbooks which are quite similar. Agreed, these factors do exist, but they need not exist forever.

A firm and steady pressure by teachers will influence *state courses* of study and examinations. Not everything in the textbook need be taught; the book is a basic reference, not a strait jacket. Texts will change as the demand is felt. Yet even the existing texts have a great deal of material from which intelligent selection can be made. Through the efforts of many committees of both college and high school teachers, the large scale examinations such as the Regents Examination in New York State and the College Entrance Examinations are already being modified. All the restraining factors are man-made and will respond to a polite form of sincere rebellion in the interests of children (see Physical Science Study Committee, p. 293).

If you could visit simultaneously many classes in physics early in September, you would find nearly everyone undertaking the same series of topics: measurement, then machines, and so on. It would seem that some ordained series of events goes on throughout the land. Yet the time is coming when each course will be designed for the type of community in which the school is located, for the kind of lives the children will lead, and for the ingenuity of the teacher.

Surely we can agree that physics is important to modern life and living. Likewise we can agree that children cannot be convinced of the importance of physics if they never come to the physics classroom. The conclusion seems obvious: revision of physics along two lines. One would result in physics being more attractive to the expert-to-be. The other would attract those who will live in a world of experts and make choices affecting their personal affairs.

America today is a land of millions of automobiles, millions of homes, and millions of refrigerators: mechanical devices abound on all sides, from can openers to cranes, from electric mixers to giant transformers. Yet, relatively

few in our population understand why the brakes are called "hydraulic brakes," and how they operate; why the claw hammer is constructed as it is; how a thermostat operates; what the ignition coil does in an automobile; how a fuse operates, and why it should not be replaced by a penny; how an electric motor or gas flame cools a refrigerator; how the gas and electric meters should be read; and so on. These are part of physics. So are $F = ma$, $E = mc^2$, $I = E/R$. So are many other basic principles which have helped make our present age the Age of Science and the Age of Satellites.

Yet the *percentage* of high school students enrolled in physics has *declined* over the past fifty years.[2] Will examining the nature of physics courses and physics teaching in the country help us understand why this has occurred?

The development of the course in physics

The development of courses in physics in America parallels closely that of chemistry (Chapter 13). Physics, however, appeared earlier (as natural philosophy) than chemistry, because it was already established as a science (especially as Newtonian mechanics) when chemical facts, theories, and laws were few and poorly organized.

The physics course offered one hundred years ago would not be unfamiliar to teachers and students today. The organization of content into the broad subdivisions still in use was already established. Instruction was, however, almost entirely by means of recitation, apparently intended ". . . to anticipate all needs and questions of the reader so that he would never have to do any thinking on matters of physics."[3]

Then in the 1860's the establishment of the land-grant colleges placed an emphasis on the vocational aspects of science. At about the same time, and as part of the "social climate," the influence of foreign practices in teaching physics and training specialists began to emphasize the desirability of intensive laboratory instruction. Once again the influence of Harvard University weighed heavily: first, with the recognition in 1872 of mathematics and physics as an optional admission program in place of the classics; and second, with the issuance in 1886 of The Descriptive List of 40 standard experiments which the applying student could offer for admission, and on which he was tested in the college laboratory.[4]

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[2] Although, of course, the total *number* of students taking physics has increased considerably; and so has the *percentage* of the high school *age group*.

[3] E. Smith and E. H. Hall, *Teaching of Chemistry and Physics*, Longmans, Green, N. Y., 1881, p. 269.

[4] For a list of these 40 experiments, most of which are still commonly performed, see S. Rosen, "A History of the Physics Laboratory in the American High School (to 1910),"

The immediate beneficial result, that of stabilizing the high school physics course, was followed in the next decades by a curious swing of the pendulum. From an extreme textbook, catechetical basis, the physics course swung to an almost purely laboratory course, ignoring textbooks and recitations. But what happened in chemistry was also inevitable in physics.

> By 1910, the laboratory had not solved the problems of physics teaching chiefly because both teachers and texts were of poor quality; passing examinations was the prime purpose of the work, and the laboratory work was not *real*—it was mainly quantitative and abstract.[5]

The unsuitability of the course as it had "rigidified" was further highlighted at the turn of the century by a changing high school population. Various professional committees began the re-examination of the aims and objectives of physics, with its attendant content and methodology; a shift away from the laboratory course was under way by 1915. Recitation and discussion periods reappeared, laboratory time decreased and demonstrations became customary.

What is the picture with respect to physics courses today?[6]

> Physics instruction in the high schools continues to be intended principally for the college bound student with an interest in science. . . .
>
> 1. Courses in physics are offered more in the 12th than in the 11th grade.
> 2. The mathematics associated with the college preparatory course is often a prerequisite or coincident study.
> 3. Boys enrolled outnumber girls by more than 2 to 1.
> 4. Enrollment in physics represents about 13 per cent of the students in the 11th and 12th grades.
> 5. The actual number of students taking physics has not changed significantly through the [recent] years although the percentage is smaller than in earlier years.

A leading textbook of physics in use one hundred years ago included the following topics of study:

matter and its properties
gravity
the laws of motion
the mechanical powers
regulators of motion (pendulum, governor)
hydrostatics
the steam engine
optics
electricity
voltaic electricity
magnetism
electromagnetism
telegraphy
the electrotype process
magnetoelectricity
thermoelectricity
astronomy

The present day teacher of physics would be completely at home in this course, but he would have to add many new devices, facts, and principles that

American Journal of Physics, 22, 194, 1954. Many of the historical sidelights are drawn from this paper.

[5] S. Rosen, *op. cit.*, p. 203.

[6] Ralph W. Lefler, "Trends in High School Physics," *National Association of Secondary-School Principals Bulletin*, Jan. 1953, p. 74.

TABLE 14-1 "What's wrong with high school physics," 1923 and 1947

1923 *	1947 †
The content of the modern physics course is not objectionable in itself, but is too bulky and needs to be cut down. The highly abstract and theoretical, the incidental and insignificant—*whatever is entirely foreign to the pupils' present purposes, present knowledge, and daily experience, and cannot be connected up with them through significant problems in whose answers they can be vitally interested—should be dropped out.* There must be a change in emphasis that will result in paying most attention to the "big dynamic things" in physics and to those facts and minor principles which are exemplified in the students' own locality, and which are therefore significant because they raise questions in whose answers the students can see some use. Minor and special principles must be justified before the pupils are required to learn them . . . In other words, definitions, principles, and generalizations are justified by leading up to them inductively through concrete problems that arise out of the pupils' previous knowledge and their spirit of wonder or intellectual curiosity. * G. R. Twiss, *Principles of Science Teaching*, Macmillan, N. Y., 1923, pp. 325-26	The number of topics or units taught during the year must be reduced. For years, physics teachers have been bewailing the steady increase in the amount of material in their courses. New material is often added, little is ever dropped. It is time to realize that it is far better to leave out *whole* sections . . . than to reach so much poorly. The course should be organized largely or entirely about problems. This principle suggests a method of work rather than material to be taught. Class activities—demonstrations, experiments, discussion—as well as student activities outside the classroom are carried on in order to obtain answers to certain larger questions which have been accepted by the class as defining worthwhile problems. . . . Physics teaching at the high school level should largely reject the college preparatory function and stress the contributions of physics to the general education of American youth. † National Society for the Study of Education, *Forty Sixth Yearbook*, Part 1, *Science Education in American Schools*, U. of Chicago Press, Chicago, 1947, pp. 210-11.

have since appeared, without dropping much from this list. The telephone, radio, television, jet propulsion, photoelectricity, the "expanding universe," atomic energy, space satellites—to name only a few—have added to physics enough content to provide at least a whole semester's work in themselves. Physics has experienced the typical growth of a course in the science curriculum, with more having been added than removed. This process has been going on for many years, and people have been aware of it. (Table 14-1 shows comments on the situation made in 1923 and 1947. Can you distinguish one from the other?) Yet the pattern of physics teaching has remained essentially unchanged.

Unfortunately, the sort of physics course proposed by both Twiss (1923) and the NSSE (1947) requires a degree of *leisure* in both teaching and learning which is not provided by syllabuses preoccupied with facts—particularly facts whose recall will be the major part of examinations to come.

Here, as in the teaching of chemistry, we encounter a major dilemma. Teachers are advised, and sometimes agree, that science courses should be taught inductively around problems significant to the students. Yet former

experience, texts, tests, and "pressures" encourage a continuation of the traditional, teacher-dominated, systematic course.

The failure of the laboratory-centered course of the 1890's, in which the student was expected to operate entirely by induction, seems obvious. The student was supposed to re-create the classical results of physics, in the same context in which the original discovery was made. But this was impossible. The student was not Boyle or Newton or Faraday. What is more, he could read what they had found; why, therefore, should he pretend to go through the same operations which had no significance to him? A clean distinction should be made between the effort to have students practice induction and the context within which they were to practice this important process. The failure was not in the attempt to have inductive study, but in the formal, academic context within which it was to be practiced. This point is still significant in current discussions, as we shall see.

Teachers currently approaching the apparent dilemma often take an easy approach: One pattern, the systematic review of past physics, is known to them; the other, based on student problems, is at best hazy and unknown, with many potential pitfalls. So course modification waits until someone else has pioneered the way. Such a reaction is understandable. Yet the need for modification is intense. In the following discussion of present course patterns and possible bases for changes, there may be suggestions which will encourage evolutionary if not revolutionary changes in your courses.

Patterns of present courses in physics

The organization of content in physics courses has shown less change in the past one hundred years than in any other science course. The classical pattern remains in courses and textbooks: mechanics, heat, sound, light, and electricity. The past few years have brought the addition of a sixth division: nuclear energy. While such organization may be defended on the ground that these areas are coherent, one is faced with the broader problem: How does such an organization further the desirable aim of integrating the various fields within physics? In effect this compartmentalization often provides the student with five (or six) "subcourses" in physics.

The textbook as a course outline

The modern text retains much of the content of the text of one hundred years ago, for the importance of these fundamental concepts of mechanics, light, heat, sound, and electricity has only been emphasized by the discoveries in modern physics. In addition, the modern text presents the principles more recently discovered and included under the heading "modern physics."

Inductive methods are prevalent in current texts. Starting with the familiar and commonplace, the pupil is led to the formulation of the basic laws of physics. Emphasis is placed on the unifying aspects of physics; as, for example, the mani-

festation and transformation of energy—the conventional units of mechanics, heat, etc.—are shown to be interrelated and not "watertight" compartments. Stress is placed on "things to do" to encourage teacher demonstration and pupil experimentation.[7]

These texts are, however, far from perfect and have drawn criticisms.[8]

While the present-day textbook in physics is markedly superior to that current only thirty years ago, the organization, the scope of the course, tends to negate these desirable features.

> Rarely can the teacher of physics today cover the content of the entire text unless he goes back to the questionable methods of previous years where the pupil is expected to "learn" the material of the text in sequence for "quoting back" during the recitation. Where emphasis is placed on the development of ideas, on the consequences and social impact of these ideas, on the methods of experimental science and of the scientist, on learning through individual study and experimentation, less content will, in general, be covered but the pupil gains confidence in his ability for learning after formal education has ceased. The teacher *under these conditions* makes selections as to content to be studied intensively and provides appropriate interlinkage between the "blocks" of intensive study.[9]

The college-preparatory course

As we have seen, the organization of high school physics courses *today* is still cast largely in the "college-preparatory" or systematic mold. What was true in the case of chemistry is also true of physics; success in high school physics is an unreliable index of probable success in physics at college. The difference in breadth, depth, and intensity of college physics compared to the high school work is even greater than that between the courses in chemistry. A great many items in college work have not even been touched on or suggested on the secondary level. Angular momentum, rotational inertia, Kirchhoff's laws, and the like are often totally new experiences to the entering freshman. Far more significant and troublesome is the greater reliance on mathematics in the presentation of the college course; many first-year courses involve introduction of the calculus.[10]

It is unfortunate, therefore, that so much of the high school physics clings to a format and a purpose for which it is no longer suited. Not all of our physics students will go on to college, and of those who do, only a small percentage will become specialists in physics.[11] Yet the "college-preparatory"

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[7] R. W. Lefler, *op. cit.*, p. 79.

[8] C. A. Compton, "The Secondary School Textbook," *Am. J. Phys.*, *21*, 537, 1953, see also W. C. Michels, "High School Physics—A Report of the Joint Committee on High School Teaching Materials," *Physics Today*, *10*, 20, 1957.

[9] R. W. Lefler, *op. cit.*, p. 79, see also Eric Rogers, "The 'Block and Gap' Scheme for Physics Courses," *Am. J. Phys.*, *17*, 532, 1949.

A. J. Hatch and D. F. Cope, "Flashback Teaching Technique Applied to a Block-and Gap Physics Course," *Am. J. Phys.*, *19*, 137-45, 1951.

[10] See page 291, under section heading, "Changes in College Physics."

[11] In a study of physics in 370 California high schools, McRary found that 70% of those enrolled in physics intended to enter college, while 17% anticipated a career in physics. W. L. McRary, "Physics Instruction in California High Schools," *Physics Today*, *10*, 25, 1957.

TABLE 14-2 College-preparatory and college courses in physics

High school *	*College* †
I. Mechanics A. Forces in equilibrium B. Forces and motion C. Work and energy D. Machines E. Optional materials 1. Mechanics of fluids 2. Molecular forces 3. More on machines II. Heat A. Heat, a form of energy B. Expansion C. Measurement of heat D. Change of state E. Heat and work F. Optional materials 1. Specific heat 2. Effects and application of evaporation 3. Meteorology 4. More on heat and work III. Transfer of energy by wave motion A. General characteristics of waves B. Sound C. Electromagnetic radiation D. Visible light E. Optional materials 1. Additional general topics 2. Sound and music 3. Optical devices 4. Further material on vision	I. Mechanics A. Nature of physics B. Liquids at rest C. Air pressure D. Vector quantities E. Accelerated motion F. Force and acceleration G. Force and counterforce H. Statics I. Work, energy, power J. Rotation K. Gravitation L. Elasticity M. Fluids at rest and in motion II. Heat A. Temperature and expansion B. Kinetic theory C. Quantity of heat D. Heat transfer E. Change of state F. Heat engines III. Sound A. Vibrations B. Waves C. Sound waves D. Hearing E. Other topics

* Syllabus in physics from *Physics Handbook*, Bureau of Secondary Curriculum Development, New York State Education Department, Albany, 1956.

† Frederick Saunders and Paul Kirkpatrick, *College Physics*, 4th ed., Holt, N. Y., 1955.

course as it exists today is attempting to make every student a specialist in subject matter, even if only on the high school level, and it apparently is not doing even that very well.

We have already seen how the advances in physics have added more and more to the *content* so that even this cannot be covered adequately. If this be the case, how can such a course hope to achieve the "extra things" of science (see Chapter 13, The Course in Chemistry) which provide for understanding by way of scientific attitudes and methods, and for emotional outcomes which will predispose the student favorably toward physics in particular and science in general at some future date?

Table 14-2 shows, side by side, a high school college-preparatory physics syllabus and the table of contents of a standard college text. Do they show any value in terms of *general*, not special, education? Suppose the student has

High school	College
IV Electricity	IV. Electricity and magnetism
A Static electricity	A Currents and charges
B The electric current	B. Elementary electrostatics
C. Magnetism	C. Electrostatic fields and generators
D. Induced electromagnetic force	D. Potential and capacitance
E Optional materials	E. Magnetism
1 Chemical effects of an electric current	F. More on magnetism
2 Terrestrial magnetism	G. Conductors and circuits
3 Some applications of principles	H. Conduction of electricity by liquids
V Alternating current and electronics	I. Chemical and thermal sources of electromotive force
A Alternating current circuits	J. Heating effects of currents
B. Vacuum tubes	K Induced currents
C. Radio	L. Generators and motors
D Television	M. Alternating currents
E. Optional materials	N. Electron properties
1. Other applications of electronics	O. Electric oscillations and waves
2 Additional quantitative work on a.c.	V. Light
3. Vacuum tubes	A. Some properties of light
4 Other applications of electronics	B Reflection and refraction
VI Nuclear energy	C. Lenses and curved reflectors
A. Structure of the nucleus	D. Vision and its aids
B Radioactivity	E. Dispersion and spectra
C. Fission	F. Diffraction
D. Thermonuclear reactions	G. Color and interference
E. Peacetime uses of nuclear energy	H. Polarization
F. Optional materials	VI. Atomics
1. Other particle accelerators	A. A survey of atoms
2. Further nuclear theory	B Relativity
3. Cosmic radiation	C. Waves and particles
	D. The outer atom
	E. Atomic nuclei
	F. Nuclear reactions

learned the formula for centrifugal force, the method of determining the specific gravity of floating solids, Lenz's law, and so on; what now? What will he do with them in ten years? How will they affect his future behavior? What will they contribute to his future understanding, vocation, and so forth? Will he even perform better in college physics, if he takes it? *Will he take it?*

Changes in college physics

For several years conferences and committees have been working to redefine more carefully the purposes of the introductory college course in physics. A major statement of results has been published:[17]

17 R. R. Palmer (Chm.), "Improving the Quality and Effectiveness of Introductory Physics Courses," Report of a Conference Sponsored by the American Association of Physics Teachers, Carleton College, Sept. 1956, *Am. J. Phys.*, 25, 417 ff., 1957.

CONCLUSIONS

1. A thorough and rigorous coverage of a limited number of topics is more effective than an encyclopedic and showy introduction to a wide range of subject matter.

2. It is probable that no course of less than six semester hours can present adequately the basic concepts of physics at the introductory level. A list of seven such concepts is given as the minimal set that should be covered.

3. Physics should be taught as a growing subject and the student should be given illustrations of problems on present frontiers.

4. Introductory physics courses should be available to freshmen. This may make it necessary for the instructor to introduce mathematical ideas, such as those *of the calculus, in order that the subject be developed* with the desired intellectual rigor. (Later, p 421, the observation is made that "introduction to the *concepts* of calculus does not imply mastery of its *techniques*.")

5 Senior and experienced staff members should engage in the teaching of introductory physics courses, in the training of teaching assistants, and in experimentation directed at the improved teaching of physics.

RESOLUTIONS OF THE CONFERENCE

1. We hold that the goals outlined . are applicable not only to pre-engineering courses, but also to all physics courses, whether for physicists and *other scientists or for nonscientists, including those taking integrated courses or* general education science courses.

2 We recommend that the AAPT actively encourage experimentation with nonconventional courses. . . .

Let us uncover physics, not cover it.

It was the opinion of the conference that a satisfactory introductory physics course could be constructed around the following seven basic principles and concepts and the material leading up to them:

1. Conservation of momentum.
2 Conservation of mass and energy.
3 Conservation of charge.
4. Waves.
5. Fields
6 The molecular structure of matter.
7. The structure of the atom.

Furthermore, these seven principles and concepts outline the minimum content which *any* introductory course must encompass in order to provide a satisfactory treatment of present-day physics . . .

Whatever the content selected, it should:

1. Consist of sufficiently few topics so that each can be treated with thoroughness and intellectual rigor.

2. Present both classical and modern physics as growing subjects, having present day frontiers in all areas.

3. *Contribute to an understanding* and appreciation *of the unity of physics.*

Three additional papers illustrate courses believed to meet these criteria in different types of institutions.[13]

[13] Gerald Holton, "*Syllabus for the One-Year College Course in Physical Science*" (Harvard), *Am. J. Phys*, 25, 425, 1957.
Walter C Michels, "One Year Introductory Course in a Liberal Arts College" (Bryn Mawr), *Am. J. Phys.*, 25, 430, 1957.
R M. Whaley, "Three Semester Introductory Course for Engineers and Science Majors" (Purdue), *Am. J. Phys*, 25, 432, 1957.

Science in our day. Physical science holds a peculiar position in our culture. On the one hand, through the applications of technology and industry it has deeply affected our everyday life. Since the last world war and the opening of the atomic age, its impact on society has increased enormously. It has become a vital element of national defense, politics, and international relations.

On the other hand, science is not as widely appreciated and sought out as other cultural elements—like art, music, history, literature—despite the undeniable interest that it arouses in nonscientists. All are familiar with the artistic and literary visions of nature. Few realize that there is also a scientific vision, a special way of feeling and interpreting nature.

The scientific interpretation of nature is not private property of science and scientists; it is part of the intellectual wealth of mankind. To partake of it and to derive full pleasure from it, some effort is necessary, as it is for the enjoyment of art, poetry, and music. Many who are not going to be poets, painters, or musicians spend time to train their ears and eyes, to learn terms, to understand techniques and methods. Few make an equivalent effort to gain appreciation of science.

To the responsible citizen a sound scientific background would also be of practical value. An increasing number of issues are affected by science. The responsible citizen of our days must be able to judge technological and scientific questions as he judges political questions, by broad lines, even though he does not understand the details. To do this, he must have a background, a frame of reference in which to fit what he hears and learns.

The scientific language. Perhaps the most important single bar to easy understanding between scientists and nonscientists is the fact that science has developed its own language, and some of this language has not yet been assimilated into common usage. All human activities have developed special terminologies to simplify the description of facts, methods, and processes. Even the art of cooking has created a terminology, for the interpretation of which many cookbooks have special glossaries. Navigation has created a richer terminology than cooking, and special nautical dictionaries were compiled. Parts of these terminologies slowly enter common usage and jointly form our common language, others remain confined in the special fields.

Science has not only created a terminology to describe its observations, but has also developed a language corresponding to a way of thinking. The scientific language is usually more precise and rigorous than common language; it uses abstractions with which most people are not familiar; it borrows formulas and notations from mathematics. It is molded on a special attitude of the mind, and, therefore, it does not easily lend itself to precise translation. Thus, popularizations of science are useful to arouse interest and to illustrate achievements, but they usually fail to convey the spirit of science; in the process of translation science becomes adulterated. For the full enjoyment of science at least some of the scientific language must be learned, and the most appropriate place in which to learn it is high school.

Science and high schools. The situation of science in high schools has been recently the subject of many discussions both among the public and among educators, and is widely known. For a brief review of it, attention may be focussed on three main factors: the student population, the teachers, the curriculum.

The basic pattern of our high schools was set over eighty years ago when only a few children went past the elementary school. A much larger proportion of children is now attending high school, and the total population of children is rapidly increasing. Forecasts for the sixties, when the "baby boom" of the late forties will reach high school age, indicate some nine million students at the be-

ginning of that decade and some twelve million by the middle of it, as against about seven million in 1954-1955.

The number of qualified high school teachers has not been increasing in the same proportion. The demand for teachers is already greater than the supply and is growing fast. This shortage is particularly acute in the case of science teachers: industries and government projects recruit more and more scientists so that fewer are left for less remunerative jobs. A paradoxical situation has ensued: as the impact of science on society is being more and more felt, and the demand for scientists is growing, the supply of teachers to prepare them is diminishing.

The third factor of the science situation in high schools is the syllabus. Several surveys were recently taken by educational groups all over the country. A special survey of physics textbooks was carried out by the American Institute of Physics, the American Association of Physics Teachers, and the National Science Teachers Association. Many of the texts were also examined by the Physical Science Study Committee. *All surveys reached the conclusion that high school physics courses present too much material, and choose that material unwisely.*[15]

The amount of accumulated physical knowledge has grown rapidly, but the time available for teaching it in high school has remained the same. The attempt to continue to survey the entire field of physics in a one-year course has resulted in a loss of depth and coherence. Since the course cannot illustrate the development of ideas for shortage of time, it is filled only with results of physics and laws to be learned by rote or through mathematical formulas. It becomes hard to understand and of limited interest. To enliven it, technological applications are often *added* and thus the bulk of material to be learned is further increased. The tendency to dress up science with the applications of its developments may stress its practical value, but further dims its cultural aspect. It fails to show science as a human activity, as the product of human thought. All the results surveyed in physics were obtained through the mental process of human beings; all the laws expressed by dry words and mathematical symbols were arrived at by men who possessed in high degree such human attributes as vivid imagination, power of abstraction and synthesis, perseverance, and patience. All this is now lost in a high school course.

Individual teachers who might like to improve the physics course are usually prevented from doing so by the existing conditions. Science teachers are usually overloaded with work: they must not only teach, but also plan, set up, and dismantle classroom demonstrations; take care of laboratory equipment; counsel students; talk with parents; attend many kinds of meetings, and often sponsor science clubs and special science activities such as fairs, exhibits, etc. If they wish to keep up with science and further their own studies, they must do so in the summer, renouncing summer employment, which they usually need to supplement inadequate salaries. Great load, low salary, and poor status in the community all contribute to general dissatisfaction. If, despite these conditions, teachers find time and energy to plan new teaching procedures, they usually meet with administrators' resistance to innovations and with lack of funds for purchasing the necessary materials. At the same time, textbooks are generally based on the traditional pattern of a physics course, and books deviating from this pattern are not likely to be accepted by either publishers or school systems. Thus the traditional pattern becomes more and more firmly established.

NATURE OF THE PROGRAM

The Committee proposes to prepare a program showing physics as an intellectual activity. The new physics course will not be aimed specifically at preparing students for college physics, nor does the Committee expect that all high school

[15] These italics are added.

students will take it *At present about one-quarter of them take physical science and the new course will address itself to the same fraction.*[14] From this group come most of our lawyers businessmen, statesmen, and other professionals who will not take science in college The Committee hopes that the new course will build a sound scientific background in this section of the population; that the resulting greater interest in science and better teaching methods will encourage more children to take science in high school and more young people with scientific aptitudes to elect science as their career.

The Committee gave careful consideration to the possible ways of striking a balance between two needs. the need of restricting the material taught in the course to allow time for illustrating the scientific method and the role of science in our culture; and the need of giving to a student a sufficiently unified, comprehensive, and wide view of the whole field of physics, to satisfy his broader interest. To obtain this balance, the Committee will prepare a course and supplement it with a series of monographs

The course will present a reduced amount of material, and will not treat it all in the same way Some scientific developments especially lend themselves to illustrate the evolution of ideas, the interrelation of various fields of human activities, the scope of physical science. These will be explored deeply, slowly, and thoroughly The field of optics and waves and that of mechanics have been chosen for this kind of treatment. Other parts will require broader coverage: thus the role of atoms in the physical world will be illustrated in many examples throughout the course. Other parts will be only surveyed. In order to stress the unity of physics and the coherence of physical ideas, the course will be focussed toward a unified picture of nature, the atomic picture. Thus the student will learn not only the physics of the past, but also the physics which is being evolved by men of our generation; which is affecting his present and his future; which is still an open field whose many paths leading to the unknown he may elect to follow.

The monographs will supplement and extend the course in awakening and satisfying the students' interest in physics and related subjects. Certain material that is traditionally taught is omitted from the textbook or offered in reduced depth or detail; the monographs will make it available to those students who seek it Beyond this, they will cover historical and biographical material, certain advanced topics that may appeal to the brighter student, technological applications, "how to-do-it" subjects, and accounts of especially stimulating periods in the history of science. Each will be written by a qualified person, in his own style and according to his own views; the student can thus become acquainted with a wide range of viewpoints and approaches Altogether, the monographs will constitute a sizable library of low-cost, paper bound books from which a student may borrow, or volumes of which he may buy for himself.

Tools of the program. In the preparation of the tools to implement the course, the committee is guided by two sets of considerations:

1. The most effective way of teaching physics is to use several methods and media concurrently Some parts of physics, like historical evolution of ideas, mathematical deductions, etc., can best be learned if *read* over and over. The significance of physical phenomena, on the other hand, will best be understood if the phenomena are *seen* over and over again. And the experimental method can be mastered both by seeing how demonstrations are prepared and carried out on film and in the classroom, and by actual experimentation in the laboratory.

2. Students must learn physics not only through the formal teaching, but also by doing *physics*. Teachers must encourage and lead students to work

[14] These italics are added.

independently, to make their own observations, and to push forward the frontiers of their knowledge. Students must *listen* and *see* in the classroom, *do* and *advance* in the laboratory and at home. Teachers and students must collaborate. In order to obtain the best results from this collaboration, there must be a carefully planned division and correlation of work between teacher and student. Experiments to be done by students must stimulate their interest and challenge their ingenuity. Thus experiments must not be too specialized, not so hard as to discourage students, and yet not so easy as to become routine work.

Among the materials which the Committee is preparing for both teachers and students are a detailed syllabus and a textbook, films and filmstrips, manuals for teachers and for students, suggestions and equipment for classroom demonstrations and laboratory work, kits for students; questions for tests and exams, for use both in the course and for college entrance examinations; placards, etc. All this material will aim at the same goal: to show physics as a product of human minds in the pursuit of truth, an activity which has evolved through the centuries and is still evolving and which has created a philosophical structure and a particular way of thinking.

There is no need to explain these materials in detail, and a few words will be said about a few of them only.

The films. Approximately one-fifth of classroom time will be given over to films. These films will be an essential part of the teaching learning process. They are not intended to provide entertainment, or to make physics more "palatable." They will serve as follows.

1. To call attention to phenomena of common occurrence, but usually not seen because they are not obviously related to known causes. An example of such a phenomenon is the interference color in an oil film on water.
2. To show unusual natural phenomena: an eclipse cannot be shown at will, but the movie can be made readily available.
3. To present demonstrations which require special apparatus and techniques and cannot be performed in high school laboratories, or which require more time for setting up than the teacher has available.
4. To show details of experiments through close ups and slow motion.
5. To make it possible to show these phenomena and experiments over and over again.
6. To supplement graphs and illustrations through the use of animation.

The manuals. The radical change in the philosophy and methods of teaching physics in high school will place a burden on teachers. They must acquaint themselves with a new point of view and master new techniques and materials. To this end, the Committee will prepare a manual which will illustrate the aims of the new course in detail and explain the reasons for the pedagogic choices; point out ways in which the aims of the course may be achieved, offer suggestions for further examples and work not included in the text; give technical instructions on the use of certain teaching aids like films and demonstration materials. The new approach to teaching will give rise to a number of questions from students for which teachers may not be prepared; the manuals will therefore provide a list of likely questions and ways to answer them.

The manual for students will include basic questions meant to lead them to constructive thinking; supplements to the films, which will integrate the subject of each film in the course; workbooks and test books.

Kits for students. It is hoped that many students will want to work on their own and experiment in various fields of physics. The Committee will make avail-

able a certain number of kits at low cost, containing materials and instructions for building simple instruments and guidance for their use. There will be, for example, an optical kit with lenses, prisms, tubes, supports, color charts, etc.; the student will be able to build telescopes, cameras, etc., and use them to make his observations

Exams. Any change in a high school course must be reflected in the exams that the student will be asked to take, and especially in the college entrance examination The Committee is taking steps, and making good progress, to achieve complete coordination between college entrance tests and the new program of high school physics.

Procedures. In the working out of this program, the active collaboration of the educational profession is being used. Educators and high school teachers are heavily represented on the Committee, and science teachers in limited numbers have been recruited for full time work Some preliminary material is now being circulated among working teachers for comment, and procedures have been established for continued development of the concepts of the Committee inside the classroom A preliminary edition of the textbook is being used in a limited number of classrooms during the academic year 1957-1958, an increasing amount of new laboratory material is being prepared and will be available.

The Committee feels that the widest possible dissemination of its work is necessary if it is to profit from the experience and the skills of the teaching profession, and the scientific community. Consequently, it intends to make available, upon request, details of its activities in the various phases of its program Progress reports on the program as a whole will be published at regular intervals, and will provoke, it is hoped, comments and suggestions

SPECIFIC OBJECTIVES [OF THE PROGRAM]

In teaching the physical sciences certain objectives must be kept in mind, and the subject matter must be organized so as to bring them into evidence. They are:

1. *The unity of physical science* Physical science aims at interpreting the world around us It cannot be divided into many independent fields because the phenomena it covers are interrelated This can be seen by the fact that certain laws, like the conservation of energy, apply to a very large range of phenomena.

2. *Coverage.* A course which does not give a fairly wide picture of the role of atoms in the physical world is essentially incomplete. Broad coverage on atoms and their use in examples is therefore desired throughout the course.

In order to show the coherence and power of physical ideas, certain narrower fields must be explored deeply, slowly, and thoroughly. The two fields of optics and waves, and of mechanics are chosen for this kind of intensive treatment.

3 *Regularities.* The observation of regularities in physical phenomena is necessary before laws covering the phenomena or models underlying them can be established.

4. *Many independent arguments for one law.* In establishing physical laws many independent arguments should be used to help show the solidity with which the laws are founded.

5 *Models.* Models are often useful to put a possible explanatory background behind observed phenomena. They often suggest relations between phenomena which can then be investigated

6. *Deduction of phenomena from laws* From laws established to correlate one set of phenomena or more, we can deduce many other physical conclusions We should make many deductions from the laws to show their power and scope. Even the simplest physical law, such as the law of refraction, can be extended from a few cases to many more complex cases.

7. *Limitations of laws.* Over the range of phenomena and within the range of accuracy for which they are established, our physical laws are not subject to future modification. The range of validity of a law may indeed extend beyond the phenomena on which it was originally based, but the applicability of laws is usually limited.

8. *New models include the old.* New models and more refined laws are occasionally established to extend the range of applicability to include new phenomena. An old model may thus be superseded by a more refined one, but we wish to stress that the new model includes the old.

9. *Controversy.* Controversy played an important role in the evolution of science. Examples of famous controversies and their significance in relation to their times will make it possible to tie science with history. In this respect one may point out that ideas and interpretations that have been discarded are still considered "scientific." The Ptolemaic model of she universe had its role and its use in the development of the Copernican model.

TENTATIVE OUTLINE OF THE COURSE

The first day of the meeting various groups presented outlines, parts of outlines, or views on preparing outlines Their approaches proved to be different more in appearance than in essence. The morning of the third day an outline was worked out at the meeting and fully accepted by it.

It was agreed that physics would be more meaningful to the student and its unity would be stressed if the presentation of the subject matter were locussed toward one goal, and that this goal ought to be the atomic picture of the universe. This does not preclude specific goals for single parts: the Newtonian picture of the universe can still be taken as the goal of mechanics. The atomic picture will show physics as an open field of knowledge, where much has still to be done, rather than as a closed discipline.[17]

I. *The universe and other things*
   - Sizes and numbers
   - Structure of universe
   - Atomic structure of matter
   - Molecular interpretation of chemistry
   - Size and numbers of atoms

II. *Light waves*
   - Rectilinear propagation
   - Reflection
   - Refraction
   - Corpuscular and wave models
   - Mechanical waves
   - Interference
   - Measurement of wave length

III. *Mechanics*
   - Inertia
   - $ft = m\Delta v$
   - Mass; force; kinetic energy; conservation laws
   - Gravitation from planetary motion
   - Kinetic theory of gases
   - Coulomb's law; $F = eE$; $F = ev \times B$
   - Induction on moving conductors

IV. *Atoms*
   - Discreteness
   - Electron charge
   - Nuclear model of atoms
   - Size, charge, mass of nucleus

In this order the emphasis moves naturally from the kinematic toward the dynamic description of phenomena.

The applied physics course

For the nonacademically minded (the science shy), or for those whose high school education is terminal, or for those going on to college but with no further interest in science, physics certainly has value in its major develop-

[17] The extreme tentativeness of this outline is to be stressed. It is being revised daily.

TABLE 14-3 An applied physics course *

I Electricity Much of the work of every day life is performed by electricity
- A Familiar uses of electricity
- B Safety procedures and devices
- C Home appliances
- D Circuits used in home wiring
- E Generation and supply of electric current

II The automobile An application of physics that has vastly increased man's mobility
- A Parts of the automobile
- B The engine
- C The fuel system
- D Ignition
- E Valves
- F Cooling system
- G Power flow
- H. Control devices
- I Safe driving
- J Care of the car

III Engines: With which man does his heavy work, and which make rapid transportation possible, make use of the principles of applied physics
- A Types of engines
- B. The gasoline engine
- C Diesel engine
- D. Jet engines
- E. The rocket
- F The steam turbine
- G The steam engine
- H. Advantages and disadvantages

IV Hobbies Science gives us greater understanding and enjoyment of the hobbies with which we occupy our leisure time
- A How music is produced
- B The phonograph
- C Tape, wire, and film recording
- D The camera
- E Darkroom techniques
- F Home movies
- G Model making and operation
- H Amateur science

V Energy. Living has been made easier by harnessing the world's energy supply to do our work.
- A. How work is done
- B. Power-driven machines
- C Types of energy
- D. Availability of energy and the standard of living
- E. Development and use of the world's energy supply

VI. Atomic energy: Science has succeeded in releasing the energy of the atom with its tremendous possibilities for peace and for war.
- A Origin of atomic energy
- B. The atomic nucleus
- C Production of nuclear energy
- D. The chain reaction
- E. Peacetime uses of nuclear energy
- F. Problems of international control

* New York City syllabus in applied physics

ment as general education. Yet the regimen of the typical college-preparatory course has not made physics "palatable" for such students.

An effort to provide for such students has come in the introduction of courses in applied physics Here, the emphasis is placed, not on the theory or concepts behind various phenomena, but on their applications. Mathematics is minimized. One need not be able to state Pascal's principle in order to appreciate the operation of the hydraulic press or brake; neither is an understanding of the mathematical statement of the principle essential to the student One need not know how to calculate efficiency in order to observe the benefits of a pulley. To know the mathematics of image formation in a plane mirror is not required in order to appreciate the properties of that image. The course in physics abounds in topics whose "teeth can be drawn" so that the student can learn to appreciate the values of the subject matter and to see why others might desire and use mathematical formulations for more precise predictions.

VII. The airplane: Applied physics has opened up the air as a highway of commerce.
   A. Parts of the airplane
   B. How the wing provides lift
   C. How thrust is obtained
   D. Supersonic airplanes
   E. Controls
   F. Safety in the air and at the airport

VIII. Electronics: Discoveries in the field of electronics have given us radio, television, and other communication devices.
   A. Essentials of the radio receiver
   B. Tuning
   C. The vacuum tube as amplifier
   D. The speaker
   E. AM and FM
   F. The television set
   G. The picture tube
   H. Radar

IX. Temperature: Applied physics has given us devices for controlling temperature in the home and in industry.
   A. Refrigeration
   B. Cooking and heating processes
   C. Thermometry
   D. Industrial temperatures
   E. The electric refrigerator
   F. The electric furnace
   G. Welding
   H. Fuels
   I. Air conditioning

X. Health: Science has given the physician tools with which to diagnose and fight disease and to improve health.
   A. Doctor's diagnostic tools
   B. Clinical thermometer
   C. Stethoscope
   D. Electrocardiograph
   E. Sphygmomanometer
   F. X-ray
   G. Microscope
   H. Radiation therapy
   I. Eyeglasses

XI. Hearing: Science has enabled man to apply the principles of sound to improve his range of hearing
   A. Factors affecting hearing
   B. Improvement of hearing
   C. Improvement of audibility
   D. Acoustics
   E. Sound recording
   F. High fidelity
   G. Ultrasonics and its applications

XII. Vision: Physical devices widen the range of information and enjoyment that we receive through our vision.
   A. Factors affecting sight
   B. Operation of the eye
   C. Types of eyeglasses
   D. The camera
   E. Projectors
   F. Motion pictures
   G. Stroboscope
   H. Telescope
   I. Color and the spectrum

One danger exists in the construction of such courses. If they are made by taking a college-preparatory syllabus and selecting the topics *we teachers* believe will be of value to the student, we are very likely to construct a syllabus which is a fair replica of the original (replete with technical vocabulary) *which will defeat the purpose of the course.*[18] A course in applied physics should instead be built from the ground up, with the student as the focus, and it should be coupled with a view to the needs and interests of the students. What might be a suitable set of problems in a big city might be quite unrealistic in a farming or mining community; what might be suitable for a seacoast town might be unsuited to an inland community. The outline (see Table 14-3) of one course in applied physics allows us to examine the subtopics; these give the flavor of the word "applied" in the course. Compare this with the college-preparatory course in Table 14-2.

[18] We are reminded of a teacher in such a course who said he taught "applied physics" when the principal came to visit, but otherwise he taught "physics."

Summary

We can illustrate at least five kinds of biology courses (see Chapter 12), and innumerable courses in general science (see Chapter 15), and several courses in chemistry (see Chapter 13), although the majority are similar to the so called college preparatory courses. Yet we can find few variants from the so called college preparatory course in physics. Changes are, however, in the wind, *viz.*, the work of the Physical Science Study Committee.

Frames for developing a course in physics

As we have indicated, there are as many ways of designing a course as there are of skinning the proverbial cat, although we probably use our ingenuity in skinning a cat at least as often as we use it in solving this problem of education. That pattern followed by the teacher in his student days is not necessarily the best experience, and it certainly is not the final experience. There are, as in the other courses we have discussed, various frames of reference which help in designing one's own course.

Conceptual schemes as a frame of reference

Physics has a flavor which arises out of the concepts and principles which are peculiar to it alone. Thus:

A body immersed in a fluid suffers an apparent loss in weight equal to the weight of the fluid displaced.

Pressure applied to an enclosed fluid is transmitted unchanged in all directions.

At constant temperature, the volume of a gas varies inversely with its pressure.

For every force there is a "reaction" force, equal in magnitude and opposite in direction.

Heat may be (partially) converted into useful work by properly designed machines.

When a magnetic field is cut by a wire, an electromotive force is induced in the wire.

An electric current in a wire consists of motion of electrons.

The sum total of matter and energy in the universe is constant.

Light, x rays, ultraviolet, radio waves, etc., can be considered to be electromagnetic radiations which travel in transverse waves and do not require a medium of transmission.

But all these may be summarized briefly. If biology places emphasis on life processes and the conceptual scheme of continuous organic change, while chemistry highlights the structure and changes of substances, then the keynote of physics is energy. It is therefore possible to subjugate all of the foregoing

(and many other) statements into one broad conceptual scheme: "Within the universe the total quantity of matter and of energy is constant; under extreme conditions matter and energy can be observed as interchangeable." This would of course be subdivided into other concepts and principles (which would in turn be subdivided). Thus:

1. The physical properties of matter, e.g., inertia, gravitation, etc.
2. Atomic structure
3. The concept of energy
    a. The forms of energy
    b. Translating energy into work
    c. Matter as frozen energy—$E = mc^2$

Such a scheme provides a common denominator for any and all aspects studied. Rather than a study of light, heat, and sound as separate and distinct topics, we have an organization which studies them together, thus emphasizing both their similarities and their differences. The claim will be made that this is also done in the traditional course of study where these are studied separately and their features then brought together, generally in the form of a table, but, in this treatment usually the "tail wags the dog." It often amounts to nothing more than a compilation of facts with the unifying concept never seen or comprehended.

Boyle's law would not now be a particular manifestation of gases; rather, it would bear relation to the kinetic energy of molecules. Friction in a machine and resistance in a wire would now be comprehensible in terms of degradation of energy. These conceptual schemes enable the teacher to cut across the relatively rigid structure of physics and treat it as a whole.[19]

Topics as a frame of reference

Select a syllabus (or textbook) in physics at random. Unlike general science or biology, more like chemistry, its organization is highly predictable (see Table 14-2). There will be five topics or "blocks," one each on mechanics, heat, light, sound, and electricity. To these has often been added in recent years a sixth, on nuclear energy. These will be subdivided further into *logical* sections; the "logic" is of the formal, after-the-discovery type. Thus, the broad field of mechanics will start with an introductory portion on the properties of matter of interest in physics, and will be followed by material on the metric system, laws of motion, mechanics of gases and liquids, work, energy, power, and machines. That of electricity will be divided into magnetism and static electricity in one part, and "current electricity" in the other. Later treatments have amplified the treatment of alternating currents as applied in radio and television.

Such an arrangement may be detrimental to the teaching of physics, in three ways. First, it divides the subject in such a way that the student is often

[19] See the recommendations of the Physical Science Study Committee, pp. 297-98 as a guide.

it has severe limitations. A topical plan does not indicate the intent of the instruction. Neither does it indicate in detail the content. A topic such as "heat" or "levers" does not specifically inform another teacher what ideas will be included, what context will be employed, how detailed the treatment will be, or where and how this topic will touch the lives of the students. The fact that most physics teachers *will* get a fairly clear idea of what is implied by topics like "levers" and "heat" is evidence of the standardization of the course that is taught irrespective of the audience.

Problems as a frame of reference

Whatever means we use to teach physics will necessarily result in the accumulation of a store of facts and principles. But what they will mean to the student, how well they will be understood, what values they will have later will depend not on a recall of the facts or principles as such, but on the way in which the student has been led to them and the variety of contexts in which he recognizes them as applicable. Consider the following cases.

A student is called to the demonstration table to use a claw hammer in removing a four-inch nail which has been driven deeply into a block of wood. He soon discovers that the removal becomes more difficult as the nail is withdrawn. He himself is aware of two questions. Why does this happen? What can be done to make removal of the nail easier?

Or a small model of a fish is placed at the bottom of an aquarium tank filled with water, and the student, in imitation of a spearfisher, is asked to push a slender glass rod through the water to strike the fish, working from a number of angles. He misses repeatedly, except from straight overhead.

Or a 20-ampere fuse has just "blown" and you have only 15-ampere fuses for replacement. Can they be used?

These situations will bring into play a host of the facts and principles that are the domain of physics. But they will have arisen out of a *problem;* they will have originated not in artificial questions propounded to initiate the study of a predetermined topic, but in an honest-to-goodness situation which may have confronted, or will confront, the student in his life. Now we involve the interest of the student and increase his effort to understand. And to answer these questions, he must utilize known facts and principles or discover them by further questions and experiments. The inductive method comes into play, and with it, understanding, appreciations, and attitudes. Emphasis on dealing with real problems helps in concept attaining, even if it is just "problem doing" (see p. 27). Problems can be used in many ways:

1. Problems can be used to develop interest in a topic. There is the problem of the spearfisher stabbing for "fish." Snell's law applies, but the students discover it for themselves, or see its meaning.

2. Problems may serve to apply facts and principles. If students who have previously, possibly in general science, learned the facts and principles

of the lever are confronted by the hammer and nail experiment, the teacher (and the students) will then know whether they have understood the principles or simply memorized the "facts." Where there is understanding, there is appreciation of the practical significance of the knowledge and where it is applicable.

3. Problems may serve to test understanding. A beaker two-thirds full of water and a 200-gm metal weight are counterpoised on a scale. If the weight is placed in the beaker so that it is fully submerged, will the weight increase, decrease, or remain the same? Or copper and tungsten wires of the same dimensions are connected, first in series and then in parallel. If 110 volts is now applied to each combination, which wire will be heated to melting first?

4. Problems may be used to stimulate individual study and research. Many new problems appear as the student shows curiosity regarding the history of scientific developments. How was the size of a molecule first determined? How can the wave length of visible light be measured? Does Boyle's law have any practical value? The problem situation then has value in terms of needs and interests.

5. Problems may be used to develop a point of view. Whose point of view? The student's of course; and in helping the student develop a position, the teacher may change his. For instance, some topics cannot be demonstrated. But a film may be used to raise the tremendously pertinent question of the use of the physicist's great contribution: atomic energy. By allowing full but informed discussion, the teacher helps the student build a point of view.[21]

Needs and interests as a frame of reference

> That material which will be of greatest interest and value to students will (1) help the student the better to understand his own behavior; (2) help to explain, through reference to larger underlying principles, the common phenomena and devices of his own environment. Material that does not meet these criteria becomes of suspect value and may be considered for deletion.[22]

Apply these criteria to such topics as the laws of capillarity, images in a concave mirror, Lenz's law, the formula for centrifugal force, and the relation among image distance, object distance, and focal length in a lens (as usually presented), and these topics are found wanting.

On the other hand, a course built around the automobile will introduce the elements of hydraulics, mechanics, and electricity in a manner that arouses interest and satisfies needs. This idea has often been suggested in the *statements* of a syllabus, but the matter has rested there. Occasional reference is made to the automobile (or other theme of interest), after which the work reduces to the usual treatment of the areas mentioned. To be effective the central theme must remain central; all of the areas must be integrated around it.

[21] A list of films is available in the accompanying volume, *Teaching High School Science: A Sourcebook for the Physical Sciences.*
[22] NSSE, *Forty Sixth Yearbook, op. cit.*, p. 210.

College teachers have often introduced novel and interest-holding central themes. For example, at Brooklyn College, Peach [23] designed an introductory course around a model railroad, which ran on the table at varying speeds, pulled loads, turned corners, puffed smoke into a "wind," etc.

No two courses based on needs and interests should be alike, because this type of course should be fitted to the group being taught. It should be capable of change "at a moment's notice." A course of this type based on the needs and interests of students in a rural community is presented in the "Excursion" at the end of the chapter.

What are some of the typical studies in physics that may be stimulated by needs and interests? Is there a photographer in the class? Challenge him to take an actual photograph with a pinhole camera. His results will reap a wealth of information regarding optics applied to the camera, but he will have accumulated this out of genuine interest. Are there musicians in the class, or a school band or orchestra? Have students sound an A on the violin, clarinet, trumpet, etc.; the meaning of the quality of sound will become clear. But there also arises a stimulus toward finding out why the qualities differ. Is there a radio "ham" in the class? Put him to work demonstrating the action of various stages of a set, etc. While these activities may arise initially out of the needs or interests of a single (or a few) student(s), they accrue to the benefit of the class as a whole. Latent interests appear, for the adolescent is interested in the undertakings of other adolescents. What they report or demonstrate will receive more earnest attention than the same material presented by the teacher. Questions from the class will reveal the limits of clear knowledge and stimulate further study.

Historical approach as a frame of reference

Some teachers prefer the historical approach. Even here the student can be stimulated to think reflectively. For instance, note how Galileo's discoveries may be used as a resource.

Ask a student what he can say about an object dropped from a height. He knows (from experience) that the longer it falls, the faster it will fall. Now ask him how he would measure the changing speed, but here, *take him back to 1600*. There is no high speed photography, no electrical timing device, etc. Now, how would he do it? And so the student is confronted with the same problem that faced Galileo. A wealth of appreciation results when the student learns how Galileo employed an inclined plane to study the phenomenon in "slow motion," as well as the realization of a subtle point: the fact that an object descending on an inclined plane is also a falling body.

Or consider the pendulum. Very definitely, the formula represents cold, hard fact, but *how* was it discovered? Start with Galileo, kneeling in a cathedral, attracted by the slow swing of a chandelier overhead. How long does it

[23] H. Peach, "Complete Physics Course Through Model Trains," *Am. J. Phys.*, *20*, 314, 1952.

take for one swing? How is he to measure it? Here the student gets an appreciation of scientific ingenuity as he too times the swing of a pendulum with his pulse beat. After the experiment has been refined with a stop watch, what other aspects might be studied? And here the *student* suggests the weight of the bob, the length of the pendulum, the nature of its materials, etc. It is not long before the relevant facts in the motion of a pendulum are *discovered* by the students, a study of the data is assigned for homework with a view to ascertaining any regularity (law) involved. This approach has made the student the center of attention by *identifying* him with Galileo, whose intellectual footsteps he has been led to retrace. There will be not just a recall of facts and principles stated in a book or by the teacher, but a deeper understanding augmented by appreciations, attitudes, realization of method.[24]

Special considerations in teaching physics

The flavor of the course

By virtue of its accent on energy, physics has one point of similarity with chemistry. None of the properties which fall into its domain can be ascertained until something is done to, or with, an object. Physics and chemistry are based on active verbs. The property of inertia is not evident until we start (or stop) a car; expansion and contraction are meaningless until the temperature changes; the refractive index of a piece of glass is not apparent until light passes through it, the rectifying properties of selenium or cuprous oxide cannot be realized until an alternating current is applied to it.

But there is an additional feature of physics on which all students will agree—its ideas are *subtle*. We expect the heavy object to fall faster than the light; but it doesn't. We learn that light is transmitted by a wave motion; but if it can pass through a vacuum, what is it that "waves"? We learn that a body submerged in water apparently loses weight, and we expect it to lose more weight on being submerged further; but it doesn't. We pull on the window pole or push on the lawn mower with a *single* force; yet this can now be divided into *two* forces. Ice water ought to cool tea and coffee as fast as ice does (it has the same temperature), yet it doesn't. And so on, *ad infinitum*. It is this subtlety in the facts, concepts, and principles of physics that may account for the impression on the part of many students (and unfortunately some teachers) that physics is a "hard" subject. But the answer should be positive, not negative. The methodology of physics teaching should be challenged to make this feature an asset, not an obstacle in the work. Problems which the children state will be attacked with enthusiasm by the "classroom detectives."

Projects that flavor the physics course differ from those in other sciences:

[24] A good example of how this approach can be applied to physics (and any other science) will be found in an unusual textbook on the college level: L. W. Taylor, *Physics, the Pioneer Science*, Houghton Mifflin, Boston, 1942.

The use of oil films in determining the size of molecules.
Experiments with Newton's rings.
Construction of wind tunnels and air-stream speed indicators.
Construction and use of a stroboscope to study motion.
Crystal, tube, and transistor radios.
Photocell experiments and solar batteries.
Construction and calibration of thermocouples.
Resonance among coupled pendulums.
Construction of a device to show a free fall of 4 feet in ½ second.
A homemade Prony brake for horsepower measurements.
Perpetual motion machine models.
Center of gravity experiments.

The place of laboratory work in physics

The kinship between chemistry and physics also extends to their problems; for everything that presents a problem to the teacher of chemistry (Chapter 13) also poses a problem to the teacher of physics. Thus, we have to choose our own blend of individual laboratory work and demonstration to help in concept attainment.[25]

Without going through the argument (p. 276) again, it is abundantly clear that both the laboratory experiment and the classroom demonstration have a central place in the high school science program. They present firsthand evidence. A considerable body of research has failed to reveal that either teaching technique is so inferior to the other as to justify abandoning it. Each has its utility, but for different purposes. In cases where the laboratory lesson appeared fruitless, one might suspect that laboratory ineffectiveness is not due to inherent weakness in this form of pedagogy, but to unimaginative, uninspired, and generally unsound patterns of laboratory procedures which should be re-examined and reconstructed in terms of the changing character of secondary school science education.[26]

Apparently no sizable study of the effectiveness of laboratory work in secondary school physics (like that of Horton in chemistry) has been made. College teachers have, however, been seriously concerned about the "payoff" on laboratory work in physics, which requires much instructional time, space, and money. Kruglak with others has carried through a series of investigations attempting to isolate, through both performance tests and paper-and-pencil tests, some evidence of what is learned in laboratory work.[27] Thus far the study

[25] Five articles on laboratory work in general appear in the *National Association of Secondary-School Principals Bulletin*, *37*, 191, Jan. 1953, beginning on p. 96.

[26] For an interesting account of how one thoughtful physics teacher gradually changed his approach to laboratory work, see R. W. Lefler, "The Teaching of Laboratory Work in High School Physics," *School Science and Mathematics*, *47*, 531, 1947.

[27] H. Kruglak and others have written a number of articles summing up the indications of the results of these investigations. This series on evaluation of laboratory work appeared, over a period of five years, in the *American Journal of Physics* as follows: *19*, 223 and 546, 1951; *20*, 136, 1952, *21*, 14, 1953; *22*, 442 and 452, 1954; *23*, 82 and 257, 1955. See also H. Kruglak, "Some Behavior Objectives for Laboratory Instruction," *Am. J. Phys.*, *19*, 223, 1951.

number choose to do a sixth experiment, even though it cannot be counted toward their grade and comes at the inconvenient time when semester examinations are being held.

Such science laboratory work stimulates a high order of learning by doing, consistent with modern educational psychology. But there is another problem which flavors the teaching of physics, even more than it does chemistry. This is the abundance of mathematics.

The place of mathematics in physics

Mathematics, like laboratory experimentation, also offers difficulty in physics, but not for reasons of expenditure or administrative schedules. The mathematical side of physics is often a stumbling block even to intelligent students.

> It might be supposed . . . that the values of science instruction which are our primary concern in general education might be conveyed more successfully without these elements [direct observation, experiment, and mathematical reasoning]. What this notion fails to appreciate, however, is that direct observation and precision are among the most important values and basic ideas that science should contribute to general education.
>
> What might be conveyed without them is not only not science, but in a very real sense antiscientific. It comes perilously close in spirit to the scholasticism with which modern science broke at its very inception. It possesses the typical scholastic reliance upon verbal authority—in this case the authority of the writer of scientific texts—it has the same predominantly deductive logical structure, and the same preoccupation with words rather than with the objects and processes which they only imperfectly symbolize. The thought that an understanding of science might be conveyed as well or better without direct observation, experiment, and mathematical reasoning involves a fundamental misapprehension of the nature of science.[31]

"Very well," one might say, "but the fact remains that students in physics cannot handle the necessary mathematics or in some cases are afraid of it. What shall we do then?"

> Many science teachers complain that their pupils have not been adequately prepared by the mathematics teachers. In the opinion of numerous educators, the mathematics teachers have just as much reason to say that the science teachers have not prepared their pupils properly . . . The transfer of the mathematical concepts taught on a symbolic basis in the mathematics classroom, to the social and scientific applications is left to the pupil. Unless a definite effort is made to *assist him in applying mathematics to science, he will continue to fail to solve* equations and formulas which arise in the science classroom even when he has *had little trouble in solving the same basic problems in the regular mathematics* classroom.[32]

What is the teacher of physics to do about this situation? Mathematics remains a language; we speak in numbers and equations as well as words.

[31] *General Education in a Free Society*, Harvard U. Press, Cambridge, 1946, p. 153.

[32] A. J. Hall, "Relations Between Science and Mathematics in the Secondary School," *Nat'l Assn. Sec. Sch. Prins. Bull.*, Jan. 1953, pp. 93, 94.

What has been forgotten by those who use mathematics as a tool is that a "foreign" language must be *translated*. Certainly the competent teacher of mathematics teaches his pupils the applications of their work in other fields, but he too is subject to the same rigors of a syllabus and schedule which are the lot of the physics teachers. Regardless of his efforts, the pupil coming to physics meets the mathematics *in a new context*. The teacher of physics will find it useless to claim that the students have been poorly prepared; they are captive in his class. He may, of course, fail these students, but this is hardly an answer. It remains instead his opportunity, even his *obligation*, to teach those mathematical concepts which are fundamental to success in physics. For example: From teacher demonstration, the class has gathered data for Boyle's law. What do they show? A graph of the data will reveal a possible relation between pressure and volume. When this is checked further, the familiar relation will be discovered. In our experience, students have often found this to be the first time when actual data obtained from experiment has been graphed. The graph comes alive. Students will often indicate that this is the first time they have understood a graph and understood the meaning of "Inversely proportional." The student does not come "ready made." We must assist him in *all* phases of our particular course, whether it be mathematics, English, or habits in general. The behavioral objectives of education remain with us (p. 86).

For a mathematical description of the world to have any significance to the student, the critical aspect is the *search for meaning*. The course must be taught with some questions always foremost: What goes on here? What pattern can I find? What can I predict and how well? In more elegant terms, the student must be searching for a *function*, a clean, concise description of a relationship among the aspects of the problem selected as probably important. Initially this will always be a *qualitative* description: As the pressure rises, a gas gets squashed or compressed. Then follows the nicer question: By how much? This second question stimulates a desire for quantitative information and perhaps a mathematical relationship, or "going-togetherness." Such a numerical or algebraic description is needed to permit predictions of "how much." Not all children will wish to go that far with each question, but they should see how the mathematical descriptions are desired and evolved, and why they are so useful.

From this analysis several conclusions appear. First, the student must be interested in the phenomenon; he must want to know something about it, qualitatively or quantitatively. Therefore, the initial context in which the problem arises must be significant to the pupil. Secondly, the qualitative analysis of "what sort of relationship do we have?" must always precede the quantitative. If no pattern seems present among observations of temperature, pressure, and volume of a gas, there will seem to be no point to looking for a quantitative result. This point is often overlooked by hurried teachers. Thirdly, with interest, a qualitative relationship in mind, and data, *time* must be allowed for the student to uncover a mathematical description and to test it. Time

will also be needed for the comparison of various results, for not all students will achieve the same answer. Which is better? What are the criteria of "betterness"? Does it satisfy more closely the existing data? Does it predict more exactly conditions later confirmed by experiments?

To many teachers a procedure such as this seems painfully slow. Since the answer (law, etc.) is known, why not tell it to them and get on to something else? Such a process, all too commonly used, leaves the student out of the creative activity. He may remember for a time, but he has not identified with the study; it is not his. Often he does not care or really understand; forgetting is rapid. The approach we have outlined is at first very slow; the student is beginning a whole new art in scientific work. But as he practices this approach, he sees his own pattern of learning and can apply it with increasing quickness to later problems. He is "learning how to learn."

By a search for functions, we mean the type of insight and logic which Faraday used in his monumental investigations. Lacking in formal education, Faraday used little or no algebra in describing his results. Yet he searched for the essential attributes (qualities) within the phenomena and found those which went together and in what kinds of patterns. James Clerk Maxwell, who applied mathematics to many of Faraday's results, said:

> As I proceeded with the study of Faraday, I perceived that his method of conceiving phenomena was also a mathematical one, though not exhibited in the conventional form of mathematical symbols.[33]

This provides the physics teacher, in fact all science teachers, with a critical distinction. Students can be encouraged to think functionally, even mathematically, without necessarily involving mathematical symbols. Many will push on to that more abstract formulation, but others can have the "feel" of how a scientist works without the algebra.[34]

An excursion, lengthier than usual, in developing one's own course in physics

14-1. In a workshop we encountered a teacher of physics who determined to try the device described for chemistry (p. 280). He tried it for two years, and it worked.

He found he could deal with the mathematical portions of physics in class; his students could read the descriptive portions. In class, therefore, he dealt mainly with topics such as optics, nuclear physics, mechanics, wave theory, and electricity. Students read by themselves, mainly about simple machines, measurement, heat, applications of physics (toasters to pulleys). He added this modification: he reviewed briefly all materials read before developing any principle with mathematical background.

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[33] James Clerk Maxwell, *Electricity and Magnetism*, 3rd ed., 2 vols., Dover Publications, N. Y., 1954.

[34] For exemplary material, you might wish to peruse M. Faraday, *Researches in Electricity*, Everyman's Library, No. 576, N. Y., 1914, and I. Newton, *Optics*, Dover Publications, N. Y., 1952. The papers of B. Franklin on electricity are also similar.

He found he had time to teach in the leisurely fashion which good teaching demanded. He could go into the highways and byways; he could deal with the methods of scientists. The class had the time to develop major concepts and conceptual schemes. the class had time to develop its needs and interests.

14-2. Another teacher of physics tried a device which we have seen operating in three Midwestern schools.

This teacher gave his class a standard workbook. He suggested this method of study: each student in the class could do each "exercise" at his own speed. The class would use several textbooks (school and college) for reference. A schedule was decided upon. each student could either go ahead at his own speed and do the exercises one after the other, or if he were ahead of schedule, he could stop after a certain block (say, machines) and do a project of his choice.

Students would take examinations on text and lab work at scheduled times.

The class was given the opportunity to discuss the advantages or disadvantages of this method. It was adopted. Is it surprising that this class did as well in its examinations as did other classes that selected the conventional method?

14-3. At the end of the spring term, 1957, Professor Harvey White of the University of California completed 162 TV lessons of a whole course in physics. Professor White taught the lessons in a TV-teaching "experiment" in the Pittsburgh schools; his lessons were also filmed in color and in black and white. Now we are not suggesting that this course replace you, the teacher (although some have seriously suggested that these films be used where there is no teacher of physics). We suggest that this provides one of the few times that teachers have the opportunity to observe another teacher at work. If the funds are available, it would be worth while purchasing or renting the films.[35] They would furnish excellent material in a critical seminar on objectives, philosophy, and teaching method in physics. Also excellent demonstrations are presented.

14-4. There are further deviations from the standard course. The following suggestion [36] is applied to a "course" suitable for rural schools. Note, however, that the generalizations have the same drift as in a "standard" course. It is in the *devices used to illustrate* the principles that the course differs.

> Here a farm lighting plant might be selected as a familiar and useful application of principles of physics worthy of study. It would be treated as a complicated device for the conversion of stored energy into forms useful in daily life. The gasoline engine would be treated as a device for converting the stored energy of the gasoline into heat, and the heat into mechanical energy for turning the electric generator. The generator would be treated as a device for converting the mechanical energy into electrical energy. The storage cells would be treated as devices for converting electrical energy into chemical energy and chemical energy into electrical energy. Various household and farm machines would be treated as machines for converting the electrical energy taken from the power

[35] Available from Encyclopaedia Britannica Films.

[36] R. K. Watkins (Comm. Chm.), *A Program for Science Teaching*, Part 1, *Thirty-First Yearbook*, NSSE, U. of Chicago Press, Chicago, 1932, p. 255.

plant or the storage cells into useful forms of energy. The electric lamp would be considered as a means of converting electricity into heat and light, two other forms of energy; the electric iron as a means of converting electrical energy into heat. Friction in the machines, necessity for lubrication, and the heat developed in moving parts of machines could be used as a means of building up the notion that energy is not lost or destroyed, but merely changed into other forms, some of which are not directly useful for the human purpose for which the machine was built. It would be possible to trace the energy stored in the gasoline back to the crude oil, the crude oil to prehistoric primitive organisms, and the stored chemical energy of these organisms to the radiant energy of the sun. Pupils might eventually see that radiant energy given off from the electric lamp in the living room on a particular winter evening came from radiant energy released from the sun ages ago. Through such study pupils might be enabled to enlarge their understandings of such generalizations as the following:

1. The sun is the chief source of energy for the earth.
2. Energy may be derived from matter.
3. Energy may be stored in chemical substances.
4. Energy is not destroyed.
5. Machines serve the purpose of changing energy into its different forms.
6. All matter is probably electrical in nature.
7. Chemical changes are accompanied by energy changes.
8. The "loss" of energy in machines is only apparent. These losses may be accounted for by energy transformations which are not parts of the useful output of the machines.
9. Electricity, heat, and light are forms of energy.
10. *Complicated machines may be reduced to a relatively few simple types of machines.*

In urban situations a similar treatment might be made of the local electric power supply. Certain extensions of the foregoing generalizations would be possible with power supplied from coal and steam plants or water power and through the increased ramifications of power supplies to modern transportation and industry.

14-5. And as we might expect in the light of the history of development of courses, there should be and there is an attempt to develop a course in physical science (see Chapter 16). This attempt is in the tradition of the development of biological science from botany and zoology (see Chapter 12).

14-6. You may find it illuminating to compare the contents and organization of several current physics textbooks. How similar are they?

14-7. In several physics textbooks, compare chapters on the same subject for the concepts included. Examine the technical vocabulary used in these books. How many of the words are clearly defined? How many are necessary?

14-8. For two units in the syllabus on applied physics (Table 14-3), list the major concepts that might be developed. To what extent would mathematical (algebraic) results be necessary?

14-9. What are the lesser concepts contributing to one of the concepts from the list on p. 302? What different experimental problems (or demonstrations) could be used to work toward these concepts?

CHAPTER 15

Inventions in science courses:

The course in general science

A note at the beginning: General science is, in a sense, the oldest of the sciences. Aristotle was a "general scientist"; so was Galileo. One could hardly call either of them a chemist, a biologist, or a physicist. General science is perhaps an unfortunate term; the adjective hardly indicates the purpose of the course. We do not say general physics, general chemistry, or general biology; we should, because these are very general treatments of the areas concerned, but we don't.

When we say "general science," precisely what do we mean? Teachers of science are inclined to agree about what "general science" in a curricular sense *is not*. It is not, for instance, biology, chemistry, physics, or physiography. It is not considered a "senior" science. Similarly, biology, chemistry, and physics are not intended for the seventh, eighth, or ninth year; they are not substitutes for general science. General science comes early in the child's experience, but it is not elementary science. General science draws its subject matter from all fields in science and thus enables the student to see science whole and develop his selective interests.

General science in grades 7, 8, and 9 (usually a required course) is perhaps the most important group of courses in the science curriculum. It is there that the student begins to see science as a way of life: interesting, exciting, full of possibilities for personal accomplishment, fun, adventure, hard work, and high purpose. To hear science teachers reflect on the fate of enrollments in physics or chemistry is saddening. Perhaps they fail to realize that the student's election of advanced courses is based upon his prior experience in the subject area.

Development of the course in general science

General science is so recent in American education that we have decided to weave its historical development into the following section.

Patterns of present courses in general science

There are teachers who think that curricular time is best spent in a special science not in a "general science," however organized, because the values of science are best attained in concentrated study. There are, on the other hand, teachers who think that before an individual studies any special science it is well for him to have a broad view of science, that curricular time in science is well spent when an "introductory science" is the threshold of the so-called special sciences.

There are those who believe that this general science course should be exploratory and should stem from the child's questions and experiences. This "exploratory science" differs from "introductory science," even though historically it stems from it; the former draws upon the student's interests, while the latter draws from chosen areas in the special sciences, which are then dealt with in an introductory way. This distinction leads to courses distinctly different in content, intent, and method.

There are others who base their curriculum upon certain aspects of modern psychology and find the needs and interests of the child a sufficiently valid source of objectives for a course in general science. These teachers discard the concept of "introductory science," or even "general science," and propose that each year be a year dedicated to the growth of the child. A year's growth is the objective, not a year's general science. Thus, such teachers use the "core" approach as a significant device for helping the pupil grow.

Now which of this variety of curricular designs are most frequently found in the United States?

Most school systems in the country have planned, or are planning, general science courses for the junior high school years: the seventh, eighth, and ninth grades. In a growing number of school systems science in these junior high school years is an extension of an elementary science experience, grades 1 to 6. Such elementary science experiences are mushrooming into existence and, if present trends continue, the next decade will see a tremendous growth in elementary science. This will result in wide changes in current seventh-, eighth-, and ninth grade science curriculums. Throughout the country there are also "spots" of general science offerings in the tenth, eleventh, and twelfth grades. These are at present experimental, or are attempts at meeting the needs of the "slow" learner. They are, however, too tentative to provide any relevant conclusions at this time. There are also attempts to meet the "needs" of the rapid learner by "handing down" a biology course from the tenth grade; we will discuss this more fully later.

The elements of curriculum design evident in the seventh, eighth, and ninth grades seem to be these:

There is an attempt to produce an ascending development of concepts through the seventh, eighth, and ninth grades. For instance, if health is taught in general science (and it usually is), then it will be included in every grade,

but the topics will be arranged in an ascending development of fundamental concepts at the seventh, eighth, and ninth grades. The enrichment at each grade level is such that increasingly complex development is evident. In the seventh grade, food patterns may be stressed, the germ nature of disease barely developed, and chemical treatment of disease (antibiotics, hormones) merely mentioned. In the eighth grade, food patterns may be reviewed, the germ nature of disease developed in greater detail, and the chemical treatment of disease developed. In the ninth grade there may be a tendency to review food patterns and germ diseases in detail and to extend the chemical treatment of disease, in short, an omnibus, even detailed, treatment. The pupil who has had three years of science will have been exposed to conceptualization in the field of health in an ascending spiral.

Similar treatments will be found in the areas of communication and transportation, weather and housing, the nature of chemical change (the atom), the study of the earth's neighbors, food making in plants, conservation, and more recently, heredity.

Although this approach is widely used, it suffers from several potential difficulties that can be seen operating in some schools. 1. Too many different topics or areas may be taken up briefly each year with the result that the course is always thin and hurried. There may not be enough time for any topic to be examined and pondered adequately. 2. In the second and third years too much time may be given to reconsidering what was supposedly learned in the previous years. One of the oldest psychological laws relating to recall describes the strong relation between forgetting and the erasing effect of subsequent learning.[1] With too many topics each year the details of each are erased by those that follow. Small wonder that children do not seem to have learned much in previous years when we operate courses in a way which encourages forgetting. 3. Furthermore, the obvious repetition of topics, unless couched in really novel contexts, may give the pupils the impression that they "have had all this before." 4. Finally, such an approach is based on formal scientific principles and can easily fail to involve the interests and lives of the learners.

An alternative approach being used in some schools involves the same general units, but treats each extensively and only once. Only four or five topics are considered each year. These provide a solid basis to which later reference and comparison can be made. One year may center on man in his biological environment, the next on man in his physical environment, and the third on man's efforts to use this environment for his own purposes. Such a design permits a more leisurely approach to each topic, more time for projects, and more unified learning.

The course of study in general science in the ninth grade falls generally into four arbitrary groups or types.

[1] See, for example, L. J. Cronbach, *Educational Psychology*, Harcourt, Brace, N. Y., 1954, pp. 391-404.

The survey course

The earliest and now practically nonexistent type of general science is the survey course, one term of biology and one term of physical science. The course outline may reflect the whim of the instructor; it is generally introductory to the special sciences which follow, especially when the latter are heavily larded with the traditional college-preparatory subject matter. It is systematic science; chemistry, physics, biology are represented as such. In fact, one such course is divided into units of these sciences (see Table 15-1).

The environment-centered course

In the evolution of the general science course toward meeting the interests of the variety of students who began to come into the secondary school in the period from 1900-1930, attempts were made to include materials which had relevance for all. This second type may be called the "environment-centered" course, since its major aim seems to be to give the pupil an understanding of his environment. Typical units are listed in Table 15-2.

In the environment-centered course we have one of the first significant attempts in science to build a course around a pervasive aim—understanding one's environment—rather than around subject matter sequences.

The understanding-the-modern-world course

As teachers began to accumulate experience with the environment-centered course, modern concepts of psychology began to permeate educational practice. The notion of *science as a way of life* began increasingly to gain

TABLE 15-1 ***A survey course in general science***

I. Biology A. Classification of living things B. The structure of living things	III. Physics A. Work B. Energy
II. Chemistry A. Matter, atoms, and molecules B. Common chemical reactions	IV. Earth Science A. Elements of astronomy B. Elements of geology

TABLE 15-2 ***An environment-centered course in general science***

I. Air II. Water III. Food	V. Our living foes and friends A. Germ and insect enemies B. Friendly amphibians, birds, and mammals C. Conservation
IV. Sunlight A. Food making B. The energy cycle	VI. The solar system VII. Transportation and communication A. Man's conquest over space and time B. Gasoline engine, motor, telephone, airplane

ascendancy over the idea of science as a body of subject matter. As a result, teachers began to lean toward courses of study which dealt more with the problems of living. Science, they agreed, should help youngsters live a better life not only by helping them understand the environment, but also by dealing with the way man modifies the environment to his own purposes. Moreover, the future of the pupil as a citizen, upon whom science had an increasing impact, came more and more into consideration. What were the science problems which citizens had to solve? How were they to solve them? These were questions which appeared to be at the base of what might be called an attempt at understanding man and his science in a modern world.

In this type of course, teachers are not willing to be restricted to a syllabus which defines the course from the beginning of the year and ends in a uniform examination. Rather they look for resource units, different ones for different communities. Subject matter knowledge of itself is not the end, it is subject matter which has significance for the community as well as for the world. A comparison of resource units for such courses (Table 15-3) with the units for environment-centered courses (Table 15-2) clarifies this difference in intent. These units may not be given in any set order; indeed, examination of courses of study and textbooks based on the approach to man's concepts of the modern world shows no definitive order. In general, however, units (I through VI) in the course of Table 15-3 are introduced earlier than those following. It must be emphasized that the teacher of this type of course shows great flexibility not only in his choice of units, but also in his use of sequence within individual classes.

TABLE 15-3 General science as an aid in understanding the modern world

I. Time and space
   A. Man's understanding of his universe

II. Man as a resource
   A. Man's way of learning
   B. Man's use of the methods of science

III. Biological production
   A. Food supply
   B. Reproduction of farm plants and animals
   C. Conservation

IV. Predicting weather
   A. Rain making
   B. Housing

V. Reproduction *
   A. Plants
   B. Lower animals

VI. Human behavior †
   A. Habit formation
   B. Learning

VII. Harvesting atoms
   A. Structure of the atom
   B. Splitting the atom
   C. Atomic energy

VIII. Increasing the life span
   A. Man's use of mutation
   B. Preventing of germ and physiological diseases
   C. Increasing the life span

IX. Doing the world's work
   A. Work, energy, horsepower
   B. Machines and engines

X. Wire and wireless

XI. Industrial processes

XII. New materials

* This is sometimes part of III.

† This may be a part of II.

It would be impossible for any one teacher to deal with all these units and their different emphases in one year, one period a day. Hence, there is a choice and a diversity of the curriculum over the three years. Although a basic text is chosen, it follows that there is a wide use of supplementary texts, library materials, reports, and many other sources.

General science in the core program

As an increasing number of studies began to emphasize the "developmental tasks" of youngsters, as educational philosophers gave increased attention to the needs and interests of youngsters, schools began to accept the notion that they were, indeed, in the main stream of life and living. Consequently, the general science course began to have its goals based upon the personal goals of young people who were in the business of growing and adjusting to each other and to society. The problems of young people in our society—problems involved in job-getting; coming to terms with their bodies; getting independence from their parents, learning to get along with their age mates of different sexes, different races, and different cultures; developing a world view; developing toward psychological and economic security—and the solution of these problems, insofar as the general science course lent itself to such solution, became the reason for existence of the course.

It seemed clear that science alone could not solve these problems, or even a tithe of them. Thus evolved the "core program," a block of curricular time (three to four periods a day) of which the youngsters' needs and interests became the center. Students' problems and the information needed to solve them became, in a sense, the resource units. This type of course in which general science plays a part might be titled, "Science as an Aid in Meeting a Child's Needs and Interests."

Instead of discrete units such as those mentioned in the environment-centered or the science-in-the-modern-world course, the units of the child-centered course might be derived from a major problem of adjustment, e.g., "Understanding Ourselves." In such a course, subject matter recognizable as science, civics, English, art, music, and mathematics is used to solve a problem of living. For instance, "Why do we behave as we do?" is a problem which may be part of such a course; all areas—civics, English, science (psychology and physiology)—enter into the solution of the problem. The teacher is not *a science teacher,* but first and foremost *a teacher.*

In a core program, teaching method involves planning with the pupils to choose the kinds of activities of the course. Committees of pupils may arrange the sequence of topics. The teacher is a guide, a chairman at times; always he is there to afford opportunities for youngsters to grow in their relationships to themselves and society. The organization of the subject matter is not, by any means, neglected.

Several cautions need to be noted. In our experience, such a course does not mean less subject matter; it may actually mean more. It may also mean

different subject matter for different groups of students in the class. But the pupils share experience, as well as information, with each other through reports, projects, exhibits, discussions, and various means of interchange.

The teacher does not abdicate in such a course. His role is to obtain *maximum* learning from each pupil in a setting which involves the pupil's interests and provides him enough time for intense, broad study and comprehension. Not only does he furnish an environment free from threats and free for growth, but he looks at the needs of each pupil, and the requirements of the community and adult life as frames of reference.

Summary

The present status of course design in general science is roughly as follows. Four types of courses exist: (1) survey, (2) environment-centered, (3) understanding-the-modern-world, and (4) the child centered core program. Of these types 2 and 3 are the most common, with type 3 gaining rapidly Courses of types 1 and 4 are scarcer, with type 1 practically nonexistent. That there are relatively few adoptions of type 4 stems in part from a lack of teachers with sufficiently wide training and with the emotional commitment to teach children rather than subjects. In part this lack also stems from the paucity of school administrators, teachers, and parents willing to examine thoughtfully their responsibilities to children rather than to academic artifacts.

The development of courses in general science has followed a sequence like this:

1900 General science as a body of subject matter

1920 General science as an aid to understanding the environment

1930 General science as an aid to understanding the modern world

1940 General science as an aid to meeting a child's needs and interests

General science teaching, like all teaching, has profited from recent developments in the psychology of learning and from improvements in methods and procedures within the classroom. The lecture is used rarely and the discussion method commonly. Projects, reports, and individual laboratory work are beginning to have a major place in general science. General science is being used as a guidance period; it is the place where teachers identify those who have "science potential" and give them special opportunities for development in their subsequent high school careers; it is also the place where pupils with other abilities or handicaps are selected for special guidance (see Chapters 8 and 9).

General science is getting to be the basic course in science because the majority of youngsters take it. Increasingly, teachers and administrators are accepting the fact that general science is a potent educational tool for the development of young people.

Frames for developing a course in general science

> General science is a course of scientific study and investigation which has its roots in the common experience of children and which does not exclude any one of the fundamental special sciences. It seeks to elucidate the general principles observable in nature, without emphasizing the traditional division into specialized subjects until such time as this is warranted by the increasing complexity of the field of investigation, by the developing unity of separate parts of that field, and by the intellectual progress of the pupils.

Thus does the British Science Master's Association characterize the nature of general science in its report.[2] It is a good statement.

Policy as a frame of reference

What does one teach in general science? When? Why?

There is widespread agreement that a continuous program in science, the study of the world, from the kindergarten through high school is desirable. Many schools are moving rapidly to make this desire a reality. In the elementary grades the science is inevitably exploratory and unsystematic. In the high school are the specialized sciences. What should be offered for the junior high school years in between?

Some teachers who are specialists in one part of science do not see the need for, and the importance of, general science. They may feel that the special sciences should be started as early as possible, and that the seventh grade is a possible time. As we shall see, this conclusion is incorrect because the students are still immature; they lack practice in scientific thinking, and their store of usable concepts is small. Furthermore, the specialized sciences are more sophisticated than those who teach them may realize. Some course which involves sharper concepts than those developed in the elementary school, yet avoids the details and intensity of the special sciences, seems to be a necessary intermediate, and this course is general science. If taught in an exciting manner, such general science will point the way toward further more narrow and intense study in the special sciences.

As a matter of policy, surely, we do not wish to permit a gap in the sequence of available science courses. In addition, we must provide effective instruction for the many who will terminate their schooling or their science schooling at the ninth grade, or soon thereafter.

The experience of children and the science courses they take. It goes without saying that children do not have experiences in only one area; modern life furnishes stimuli in all areas. Science is no different. General science, which is not meant to exclude experience in any of the fundamental sciences, feeds the curiosity and interests of children whose experiences are fresh ones, day in, day out.

Of course, one may propose that children should begin the discipline of specialization as soon as they can, say, in junior high school. Why not "expose the kids" to biology, chemistry, or physics as soon as they can take it?

First, we tried it, and we shall describe this experience. Second, this works in reverse as well, one can give general science or rather "science" for six years (grades 7 12). We tried this too, and we shall describe the results.

Substitutes for general science. In the period from 1947-1950, at Forest Hills High School, an attempt was made to substitute earth science for ninth grade general science in the usual four-year sequence (——, biology, chemistry, physics). We chose two classes of superior students, each class with the range in I.Q., reading, and mathematics detailed in Chapter 9. One class (35 students) had the sequence earth science,[3] biology, physics, chemistry. The control group had the more usual sequence: general science, biology, physics, chemistry. We planned to substitute, in successive years (ending in 1953), each of the courses (biology, chemistry, and physics) for general science. After the third year, before physics was substituted for general science, the "experiment" had to be abandoned, for these reasons.

First, our basic assumption was incorrect. The preparation of children in science through the first eight grades is not uniform at the present time. Some students had had a great deal of science; others very little. Some had had "nature study" science; others "sporadic" science. This would ordinarily not be critical were it not for the factors that accompany the onset of adolescence. Puberty is a difficult period. Picture the anxieties of children, eager to succeed in high school and of the caliber which gives them the ability to succeed, faced with a course which assumes some uniform experience in science. Also, the course (say, chemistry, even biology) assumes some kind of discipline in study, an ability to take laboratory work in stride, and a bit of familiarity with mathematics.

After the third year of this kind of experimentation we found that only approximately 35% of those who had had, in the ninth grade, earth science, 40% of those who had had biology, and 30% of those who had had chemistry were planning to take three more years of science, as compared with 85% of the "controls," who had had general science in the ninth grade.

An analysis of the situation revealed other considerations:

1. It seems that children given an exploratory course in the first year of high school benefit from its *guidance function*. They use it to plan further experiences along their interests. Thus general science, if it is a broadly conceived course touching different areas of life, opens up many vistas in further course work, as well as in vocations.

2. Adolescence being a period of stress and strain,[4] it is healthy to give youngsters a good base consisting in a "new view," not review, of the concepts

[3] Course of study similar to that detailed in the "Excursion" at the end of this chapter

[4] See, for example, A. W. Blair and W. H. Burton, *Growth and Development of the Preadolescent*, Appleton-Century-Crofts, N. Y., 1951

A. J. Jersild, *The Psychology of Adolescence*, Macmillan, N. Y., 1957.

they "should have studied"; and, at the same time, to point their energies in a new direction.

3. The maturity or age of students makes a difference. Students in the tenth, eleventh, and twelfth grades achieve higher grades than do their younger counterparts of equivalent I.Q., reading, and mathematics test scores who take the same course in the ninth grade. When biology and chemistry were offered in the ninth grade, seven out of ten of these able pupils scored below 80% on the achievement scale. Of the comparable students who took biology in the tenth grade and chemistry in the eleventh grade, after general science in the ninth grade, seven out of ten achieved scores above 90%.[5]

This lower achievement in biology was somewhat surprising, although the lower achievement in chemistry had been suspected as likely. Among the many factors that might account for this lower achievement in biology were the high vocabulary load of new words and the involvement of mature abstractions such as evolution and chromosome theory.

We were forced to the interesting conclusion, still tentative, of course, that if biology, chemistry, physics, or earth science were to be given in ninth grade, they would have to be given at the level of general science; that is:

1. They would need to be so broadly conceived that each course would take in elements of the other courses. This would assume a guidance function; namely, students would maintain their interest in taking the other science courses so that they would achieve a broad scope. In other words, if, as a general practice, the so-called specialized courses were given in the ninth grade, even to the best students, registration in subsequent science courses could conceivably be reduced unless science were required of all. In other words, *reductio ad absurdum*, biology, chemistry, physics, and earth science *could* be given at the ninth grade level, if they were broadly conceived to touch all the areas of life—that is, if they were general science courses!

2. There is value to an introductory, exploratory course, either as a first course, or as a capstone course. But this should be given, it is our present opinion, on the maturational level of the students. There seems to be a level of maturity needed to envelop and develop certain concepts. Thus, while we should not underestimate the intelligence of these students (this is especially shown in their development of skills in mathematics), we should not overestimate their cultural and social maturity.

General science as a substitute. Just as it seemed logical to substitute earth science, biology, chemistry, and physics for general science, so it seemed logical for us to try to substitute general science for these courses. That is, we organized a class of superior students and gave them four years of general science, during the period 1947-1950. This attempt was more "successful" than the preceding one which substituted special sciences for general science. But even so, when we tried a four-year course in science with a second group, we were forced to abandon the trial at the end of the third year.

[5] Earth science was not offered in grades 10, 11, or 12.

The first four-year group—Science, Four Years, as it was designated—underwent the study of science in a curricular design as described in the "Excursion" at the end of Chapter 18 Possibly, it is not proper to call this four-year course a course in general science, we consider it, as we have said, a course in science. Nevertheless, in the current usage, any course which cuts across the lines of biology, chemistry, and physics is "general science."

Because of the structure of the course, the New York State Regents Examinations (in biology, chemistry, and physics) were taken by the students in their eleventh and twelfth years, biology at the end of the eleventh, chemistry in the middle of the twelfth (February term in the senior year), and physics at the end of the twelfth The mean scores were very similar (a bit higher, but not significantly) to scores for the "control" students (matched for sex and I.Q, reading, and mathematics scores) in the regular courses. But most important:

1 Students saw science whole, and they saw it in its application to life and living rather than in compartmentalized areas.

2. One teacher taught the course through all four years and thereby got to know the students very well.

3. Project work, committee work, field trips, all cocurricular activities were planned with ease.

4. In all their work, students saw that biology, chemistry, and physics could apply to a single problem, e g, levers, muscle chemistry, nutrition, and biological structure when the function of muscle was being studied, the chemistry of gasoline, the physics of motors, the psychology and biology of the driver when automobiles were being studied (see Chapter 18 for a full description of the course).

When the second group was organized, a similar organization of subject matter was attempted. However, it was thought that two teachers might participate this time. The second teacher eventually went over almost completely to teaching physics as physics, and taught the accepted syllabus.* His reason for this seems to have been mainly to prepare the children for the Regents examination. Apparently, he was not convinced that boys and girls (15 18 years of age) given an interesting course in whatever context could prepare themselves—with the teacher's aid, of course—for reasonably constituted examinations. The problem of getting teachers who would move away from their traditional trajectory was too difficult. It was easier, in short, to modify existing courses, and introduce into them concepts and methods that related more closely to the lives the youngsters were leading and were expected to lead. This, of course, with due regard to scholarship.

* The course was continued for several years, but it was not possible to get more than two teachers to give it. A course of this sort requires wide training on the part of the teachers participating.

it stems from the significant experiences and problems of the boy or girl, but is guided by the experiences of the scientist. For example, we may study burning, but it is not enough to know the basic factors (kindling temperature and fuel) which are responsible for burning; it is now necessary and possible to interpret the combination of fuel, oxygen, and kindling temperature in the light of the principle underlying oxidation and combustion, and to apply it to internal-combustion engines, and so on. Still further, general science is an exceedingly useful curricular invention for teaching the ways of the scientist in the different sciences; it is not sufficient to segregate these "ways" in their application to only one area. From the viewpoint of general education, then, general science is a most useful curricular invention.

General science, for all its broadness, maintains an integrity; it touches *all* areas of life. It serves *all* young people, and practically all young people remain in school at least through the ninth year. Hence, general science is an experience common to all. In fact, in many junior high schools it is part of a "common learnings" curriculum.

This does not exclude the possibility that for the science prone, special interests may be followed. But these interests are specific; for instance, a ninth grade youngster does not become interested in *all* of biology; he becomes interested in some area of biology, such as genetics or animals or frogs or snakes. His interest isn't in *all* of chemistry, but in photochemistry or dyes, or in just working in the laboratory.

These are some of the considerations which compel us to consider general science as a definitive area in education of children, if not in the sense of an area of academic investigation. We quote from the General Science Syllabus Committee of New York City on this subject:[7]

THE OBJECTIVES OF THE GENERAL SCIENCE COURSE FOR GRADES 7, 8, AND 9

The objectives for the course of study in general science, grades 7, 8, and 9, are based on the following considerations.

The first is the nature of the child. There is wide variation among individual students with respect to maturity, ability, previous experience, interests, and needs, both in and out of the school environment.

The second consideration is the nature of the broad purposes of education at these grade levels. It is generally recognized that educational activities of this stage, in which a child is expanding his conception of his environment and of his universe, are in a large measure exploratory.

The third consideration is the relation of the study of general science to the complete education process. The aims of a course in *general* science should be closely related to the aims of general education.

The fourth consideration is the type of approach to the study of general science that should be recommended in the course of study. The approach in

[7] Throughout these chapters on courses of study (in biology, chemistry, and physics) we have sketched the various courses, a multitude of them, as found throughout the nation. The courses delineated in these chapters are either taken directly or modeled after courses published in 33 city, county, and state curriculum departments. In this chapter we desire to show how one city has modified its state requirement to fit its own situation. Hence, for the previous section on development of general science courses we have drawn from information available throughout the country, in this section we shall restrict ourselves for our major purpose to New York City and New York State.

this course of study is based on large problems, of direct interest to adolescents, which offer purpose and direction to the learning process.

Finally, there must be the recognition of general science, as the child's first introduction to science, as a specialized area for uniquely organized experiences. In this course of study, the child's former science experiences are being reoriented into a more mature pattern of understanding of the nature of things in his world.

These considerations, then, have guided the acceptance of the following objectives, adapted from those listed in the 1947 Yearbook of the National Society for the Study of Education.*

1. Growth in functional understanding of scientific phenomena that are part of the child's environment.

2. Growth in development and understanding of scientific concepts and principles that function in children's experiences and help to explain them.

3. Growth in the use of the manipulative, experimental, and problem-solving skills which are involved in investigations in the area of science.

4. Growth in the development of vocational and avocational interests in science.

5. Growth in such desirable habits and attitudes as open-mindedness, intellectual honesty, suspended judgment, and respect for human dignity.

6. Growth in appreciation of the contributions and potentialities of science for the improvement of human welfare and in appreciation of dangers through its misuse.

7. Growth in those moral and spiritual values which exalt and refine the life of the individual and society.

Scope and sequence as a frame of reference

At hand are 62 courses of study in seventh-, eighth-, ninth-grade general science, prepared by counties, states, cities, and urban and rural communities. The strange, perhaps sad, perhaps wise, consistently noticeable attribute of these courses of study is that over the three years the content area is decidedly similar for *all* the courses of study. There are differences in emphasis. There are differences in sequence. There are, indeed, differences in statement. But even the casual observer can note that.

1. If a child were to move from Seattle to Miami at the end of the ninth year, his exposure to the content of science would have been the same for at least 95% of the subject matter taught in all the states, no matter what curriculum or what textbooks he had used.

2. If a teacher were to travel from city school system to city school system (particularly the large cities) in the United States with a file of reference materials, films, filmstrips, activities, projects (see Section V, Tools for the Science Teacher), he would find approximately 90% of it applicable.

To put it another way, for the majority of students (excluding the "gifted" or the "very slow") the content of the three years of work in general science, although still the most flexible of all areas in science, is approaching uniformity. It will be remembered that senior high school science approaches

* NSSE, *Forty-Sixth Yearbook*, U. of Chicago Press, Chicago, 1947, p. 142.

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a uniformity which amounts to standardization; physics is almost inflexibly standardized, chemistry less so, but quite uniform; biology still less so (see Chapters 12, 13, and 14).

As an illustration let us consider the general science content proposed by one of the states, then let us see what a city within that state has done to develop a scope and sequence (through selection, adaptation, and modification of content) of its own.

New York State was among the first, if not the first state to develop a course in general science. If you study textbooks in general science, you will see the unmistakable tendency of the authors to adopt or adapt the New York courses of study.[9] Put another way, New York State and its boundary states supply a major share of the authors of textbooks. Be that as it may, the course of study presented below envelops 95% of the stated content of the courses found in the United States.[10]

> A good general science program is custom built, tailored to fit the interests and needs of the pupils, the interests and background of the teacher, and the local resources available for instruction. It will differ from school to school and from teacher to teacher. It will change from year to year. It will be flexible and never rigid and arbitrary.
>
> No two teaching situations are alike. Pupils have different backgrounds and different interests. Teachers have different talents. Environments differ. Facilities for instruction differ. General science programs should differ also, each being adapted to the situation in which it is being used.
>
> The materials outlined in this section present several alternative plans upon which a good general science program can be built. Though it is the responsibility of each school to select the plan which will best meet its needs, certain minimum requirements must be met in order to insure comparable educational opportunities for all pupils in all New York State schools.
>
> SUGGESTED SCOPE OF CONTENT
>
> *Kinds of living things*
>
> Familiar living things: studying plants and animals around the school, identifying common forms, keeping living things in the classroom; making and exhibiting collections.
>
> Problems of living things: their needs, how common forms meet their needs, how living things affect each other; importance of microscopic forms.
>
> Habitats: kinds of habitats in the neighborhood; characteristics of different habitats, effects of organisms on their habitats.
>
> Man and living things: how man changes the environment; how man makes use of living things, how man is affected by living things, microscopic life and effects on man.
>
> *Keeping healthy*
>
> Nature of the human body: the skeleton and muscles; the senses, some of the major organs.
>
> Personal appearance: variation in individuals; selection of clothes; grooming of hair; care of skin; oral hygiene; posture; effect of proper and improper habits.

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[9] New York State enrolls nearly 10 per cent of all the school children in the country.

[10] *General Science, an Outline of the Scope and Content of the Syllabus*, Bureau of Secondary Curriculum Development, N. Y. State Education Department, Albany, 1958.

Diet: kinds of foods; nature of digestion; absorption; values of different foods; the balanced diet; harmful foods and eating habits.

Control of the body: the nervous system; the ductless glands; process of learning, forming and breaking habits; solving of personal problems; mental illness.

Medical examinations: nature of medical examinations; purposes; desirability for regular examinations.

First aid: types of common emergencies; knowledges needed for treatment; skills needed; limitations of first aid.

Using electricity

Permanent magnets their kinds, properties and uses; magnetizing and demagnetizing; the earth's magnetism; compasses

Electric charges nature and properties; how produced; how detected; familiar examples.

Electric circuits; series and parallel circuits; switches; tracing circuits in familiar devices.

Electromagnetism: how produced, properties, common uses.

Electric currents: from chemical changes; electromagnetically induced; how measured, voltage, energy measurement; a.c. and d.c.; transformers; transmission lines.

Applications of electricity heating devices; electric lighting; communications; motors, electrochemistry.

Safety with electricity; insulation; fuses and circuit breakers; personal hazards; safe practices

Lifting and moving things

The pull of the earth: using, measuring.

Lifting heavy objects pulleys, windlasses, ramps; levers; screw jacks; derricks; elevators.

Increasing speed and increasing force: gears; belts and pulleys.

Using and reducing friction rollers, wheels, ball and roller bearings; lubrication; brakes; increasing traction.

Buoyancy: nature of buoyancy; factors affecting buoyancy; ships; submarines.

Airplanes. pressures in still and moving air; forces acting on an airplane; propellers, rockets, and jets; controlling airplanes; operating airplanes; safety in and around airplanes.

Automobiles: general features; gasoline engines; the electrical system; power transmission to the wheels, the cooling system; brakes; care of automobiles; safe operation of automobiles.

Common chemical changes

Chemical reactions: nature of changes involved; elements and compounds; energy relations; forms of energy involved in chemical reactions; catalysis; degrees of chemical activity.

Combustion: properties of oxygen; conditions needed for combustion; characteristics of flames; products of combustion; extinguishing fires; preventing fires.

Water: chemical nature of water; importance in chemical reactions; solutions; factors affecting solution; recovering solutes and solvents; crystals; hard water; soap and water softeners; purifying water.

Acids and bases: common examples; indicators; familiar reactions and products formed; importance of acid base reactions.

Other common chemical processes in the home.

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>
> *Kinds of living things*
>
> Familiar living things: studying plants and animals around the school, identifying common forms; keeping living things in the classroom; making and exhibiting collections.
>
> Problems of living things: their needs, how common forms meet their needs, how living things affect each other, importance of microscopic forms.
>
> Habitats: kinds of habitats in the neighborhood; characteristics of different habitats, effects of organisms on their habitats.
>
> Man and living things: how man changes the environment; how man makes use of living things; how man is affected by living things, microscopic life and effects on man
>
> *Keeping healthy*
>
> Nature of the human body: the skeleton and muscles; the senses; some of the major organs.
>
> Personal appearance: variation in individuals; selection of clothes; grooming of hair; care of skin; oral hygiene; posture, effect of proper and improper habits.

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[9] New York State enrolls nearly 10 per cent of all the school children in the country.

[10] *General Science, an Outline of the Scope and Content of the Syllabus*, Bureau of Secondary Curriculum Development, N. Y. State Education Department, Albany, 1958.

commended, is its recommendation of flexibility, not of slavish adherence to the scope suggested.

Now let us examine a *sequence* based on the scope outlined above. This illustrates what one school system (New York City) has developed as its own curricular invention in general science.

Note how the sequence reflects the increasing maturity of the students: as they grow older they plan their time better and can accomplish more; the amount of time available for science study: three 45-minute periods per week in the seventh and eighth years, and five 45-minute periods per week in the ninth year, and the individuality of the community: teachers and supervisors work together to prepare the course of study.[11]

THE ORGANIZATION OF THE GENERAL SCIENCE COURSE
(New York City)

> The content of this syllabus is planned to meet the stated objectives. To achieve this purpose, the child's world has been grouped into large, meaningful experience units. In turn, these units have been further broken down into subtopics presented as problems.
>
> It is expected that each science teacher will explore *every* unit for each grade. This means that, in the three-year course, a child will study nine units—*no entire unit may be omitted.* Furthermore, in the study of these units, *no major problem may be omitted.* Each has been included because it deals with some major concern of life.
>
> Obviously, a fair and equitable amount of time and attention should be devoted to each of these major problems. However, the choice, sequence, and time allotment of topics within each unit will be the responsibilities of teachers and pupils. The teacher is strongly advised to consult with his supervisors and colleagues, and to canvass the maturity, interests and needs of his pupils before he formulates his term plan. He must be able to estimate, on the basis of the particular situation, how many lessons and how much emphasis to give to each lesson topic.
>
> Each problem in this syllabus is developed as a "resource unit," offering a variety of approaches for differing interests and levels of ability. But these are merely suggestions. It is expected that the conscientious and experienced teacher will try other approaches and methods, *consistent with safety and good taste,* and that the successful techniques will be made available to other teachers through professional associations and publications.
>
> *Outline of the course of study*
>
> Grade 7: You and Your Place in This World
> Unit 71—Getting Acquainted with Yourself
> Problem 71.1—How do we learn what is going on around us?
> 71.2—What are our daily needs for keeping health?
> 71.3—What are some of the ways that a doctor checks on our health?
> 71.4—How do some systems in the body work together?
> Unit 72—Getting Acquainted with Your World
> Problem 72.1—What are the sources of our food supply?
> 72.2—Why is the use and conservation of water a concern for all of us?

[11] *Experimental Course in General Science,* mimeographed; reproduced by permission of the Supervisor of Science, Junior High Schools, New York City, 1958.

The atmosphere

Properties of air: takes up space; weight, compressibility; effects of heating and cooling

Atmospheric pressure: indications of air pressure; measuring; common effects of air pressure, uses of air pressure.

Sound: nature of sound, causes of sound; transmission of sound, characteristics of sounds

Components of air: percentage composition; oxygen and some of its properties; carbon dioxide and some of its properties; dust and its sources; forms of water in the air, factors affecting evaporation and condensation.

Air currents: causes of air currents, effects; use of air currents in heating and cooling homes.

Weather: factors of weather; measuring weather factors; causes of weather changes, weather prediction; climatic factors.

The earth and sky

Stars: nature of the stars; star groups; apparent motions of the stars; determining the location of stars.

Solar system: the sun, nature of the planets; apparent motions of the members of the solar system; theories about the solar system.

Time: measurement of time; time around the earth.

Locating positions: latitude and longitude; determining latitude and longitude, finding directions; determining elevation; kinds of maps; mapping and map reading.

Rocks and soil

Rocks: the rocks of the local environment; characteristics of common rocks, uses of rocks; formation of rocks; making of artificial rocks; uses of artificial rocks.

Erosion: agents of erosion; products of erosion; structures formed by erosion, transportation of erosional products; deposition; structures produced by deposition.

Soil, formation of soil, kinds of soil, importance of soil; conservation of soil

Water: water in the soil; the water table; water movement in the soil; factors determining the amount of water in the soil; safe drinking water; water for waste disposal; water for power; water for transportation; water for recreation

Survival of living things

Reproduction of plants: germination of seeds, flowers; pollination and fertilization, seed development; seed dispersal; asexual propagation.

Animal life histories: life cycles of some common egg laying animals; life cycles of some common animals that bear living young

Balance of nature: interdependence; factors that affect balance; how man affects balance.

Conservation of living things: importance of living things to man; forest management; wildlife management; humaneness.

In addition to the content stated—note that it is a *scope, not a sequence*—the publication suggests different kinds of sequences, different materials to be selected from this over all scope for different kinds of students: gifted, average, and slow. A healthy aspect of this course of study, one highly to be

seventh or the eighth year. Schools on an hour program shall provide two 60-minute periods (as a minimum) in the seventh and eighth years and four 60 minute periods (as a minimum) in the ninth year (or for a combined seventh and eighth year) as equivalent to the time allowance for 45-minute periods.

We have included these samples of scope and sequence not only to illustrate the nature of general science courses as they appear in practice, but also to serve the reader as a basis for developing his own course of study. There is much elasticity in the course; any important interest can and should be followed up. Thus more time can be spent on a topic which has caught the imagination of a class, of a group, or of an individual. Material is uncovered, rather than covered.

Furthermore, the kind of elasticity and flexibility which is part and parcel of the approach to general science permits the searching out of individual students, their ability and their propensity or, as we termed it in Chapter 9, both their genetic and predisposing factors. In addition, the course enables the science teacher to take time, in the full spirit of guidance, to open up to students the vista of opportunities in science in the high school, in college, and in the world. In one junior high school which we visited, a week's time (five class periods) was spent each year on discussing future science work. This led to individual conferences which were carried on during laboratory periods, and before and after school.

Conceptual schemes as a frame of reference

We have indicated on p. 317 the kind of content which seems to be utilized throughout the country. The content clearly draws from all of science. In a preliminary or introductory way, nearly all the major conceptual schemes of science are involved to the extent that children find them useful. Possibly this is the way it should be, since at present not all youngsters go through high school, although almost all go through the ninth grade.

How far does a teacher go in developing any single conceptual scheme? The answer lies in two directions:

1. A teacher goes as far as he can by giving individual students who are willing and able the opportunity to go as far as they can. (See Chapters 4 and 9; see also Section V, Tools for the Science Teacher; see also "projects" in the accompanying volumes in this series.)
2. A teacher is limited by the mathematical skills of the students in the class, unless he is in a core program or a course flexible enough that he can develop the new mathematical skills needed at any given point.

We have found curricular schemes which enabled students to go as far as to design a simple binary digital computer, to build a small telescope or a small rocket, to maintain a museum, to develop the genetics of *Drosophila*, to read with understanding Girard's *Unresting Cells*,[12] to begin the calculus. This work

[12] R. W. Girard, *Unresting Cells*, Harper, N. Y., 1949.

72.3–How are we affected by the air around us?
72.4–How does the weather affect our mode of living?
72.5–How do the movements of the earth (as a planet) affect us?
72.6–What is the place of the earth in the universe?

Grade 8. How Science Helps Us Meet Our Basic Needs
Unit 81–Increasing and Improving Our Food Supply
Problem 81.1–What kinds of foods are needed for an adequate diet?
81.2–How can we make better use of the foods we have?
81.3–How can we increase our food supply?
Unit 82–Increasing and Improving Our Use of Natural Resources
Problem 82.1–How do we get some of the raw materials we need in industry?
82.2–What facts do we need to know to choose clothing wisely?
82.3–How are dwellings made and serviced for good health and safety?
Unit 83–Making Work Easier
Problem 83.1–How does the energy available to man affect his standard of living?
83.2–How do machines enable man to perform difficult tasks more easily?
83.3–In what other ways can machines help man?

Grade 9: A Better World Through Science
Unit 91–Speedier Transportation
Problem 91.1–Why is improved transportation important to us?
91.2–What makes an automobile or truck run?
91.3–What makes an airplane fly?
91.4–How are boats propelled?
91.5–How are locomotives driven?
Unit 92–Improving Communication
Problem 92.1–How do present methods of communication enable people to understand each other better?
92.2–How do we use sound for communication?
92.3–How may signals be transported over wires?
92.4–How do we use our eyes for receiving communications?
92.5–How can proper illumination be obtained and maintained?
92.6–How can we make a permanent record of events as they occur?
Unit 93–Prolonging Your Life
Problem 93.1–What functions of the body maintain good health?
93.2–What are some causes of ill health?
93.3–How are infectious diseases controlled?
93.4–How has the use of chemicals contributed to better health?
Unit 94–Our Atomic World
Problem 94.1–Why is radioactivity of concern to us?
94.2–How is radioactivity explained?
94.3–How is energy obtained from the atom?
94.4–What are some present and future uses of atomic energy?

Time allowances. In accordance with the recommendations of the Board of Regents of the State of New York,* a minimum of three 45-minute periods shall be devoted to this course in the seventh and eighth years and five 45-minute periods in the ninth year. In schools combining the seventh and eighth years, a minimum of five 45 minute periods shall be devoted to this course in either the

* *Science 7-8-9*, Bureau of Secondary Curriculum Development, New York State Education Department, Albany, 1956.

CO_2 is used, that glucose is the raw material of photosynthesis, and that O_2 is a by-product of the process.

In biology or in physics the teacher may deal with the photosynthetic effect of different wave lengths of light by having elodea placed in test tubes wrapped in blue, yellow, and red cellophane. Of course, if the students indicate a strong interest based on prior experience, the entire sequence could be developed in earlier grades. The readiness of the students is more important than the particular grade in which they happen to be enrolled.

In short, repetition in a new context is an aid, not a hindrance to concept building. Concepts must be built *on* something, and that something is the previous experiences and concepts which the children have developed. Finally, who knows what happens in the brain of a boy or girl? What happens when a student hears something or sees something he has experienced before? What are the advantages and disadvantages of having it in a new context?

Special considerations in teaching general science

Note that in the preceding three chapters we have included a section in which we have considered the *flavor* and the *problems* in the course. It is for this reason especially that we have placed the consideration of general science after that of the other courses. General science is a *derived course*, taking not only its content, but also its flavor and problems, from the major science areas.

Except for one thing: the students are much younger, and their lack of maturity (i.e., experience) makes certain areas particularly sensitive ones. These areas are the sensitive ones of our generation: sex behavior, religion, and so forth. Hence, most general science courses avoid these areas. This lack of maturity or experience also limits the amount of mathematics which can be used in the course; hence the physics and chemistry taught are almost always descriptive.

An excursion into developing one's own course in general science

15-1. We urge you to get this excellent set of materials; they were carefully developed by teachers for use in general science by the State Department of Education, New York State, Albany:

The General Science Handbook, Parts 1, 2, and 3. More than 2,500 carefully selected science learning activities are included in the three volumes. A cross index to all three volumes is included in the syllabus, *Science 7-8-9*, 1956.

General Science Survey Tests, Forms A and B. Packets for each form contain 25 booklets, 25 answer sheets, 3 class record sheets, 1 answer key and 1 manual.

was done by giving individual students, or groups, the opportunity to work in a corner of the classroom, a basement or room in one of the student's homes, the laboratory before and after school, or a corner in the laboratory of a local university.

The question is not where one can limit the conceptual schemes, but how far one can go. And what will happen in the senior sciences, say biology, if a youngster "knows" Mendel's laws: or in physics, if a boy or girl "knows" the laws of the period of the pendulum, or in chemistry, if a student "knows" the structure of chlorine? What a wonderful opportunity to extend that boy's or girl's knowledge and skill! What an opportunity to increase the ranks of scientists!

This leads us to one of the nagging problems in teaching any subject which is "introductory" to another in the same area. How does one avoid repetition of content? Actually this is a curious question.

What would an English teacher say if one were to ask, "Why should students reread this poem? They've read it once. Why reread *Macbeth* or *Hamlet*? We've all read them once." An English teacher would say that one benefits from rereading a worthwhile hit, poem, play, or book; one benefits from contemplation; the book does not become a better book through re-reading and contemplation, but we become better people. We see in the material new ideas, new depths of meaning to which we were not sensitive earlier. For example, Lewis Carroll's *Alice in Wonderland* is to children a fantastic, amusing, topsy-turvy world, while to some adults it is a rich social satire.

Similarly, a mathematics teacher would not be concerned about the repeated use of arithmetic or algebraic operations.

Surely the possibilities of scientific topics, say genetics or optics or human behavior, are not exhausted by preliminary explorations in elementary and junior high school!

Teachers in general should be concerned only if the subject matter is repeated in the same context and for the same purposes, e.g., learning how to "name" the poles of a magnet. Skillful teachers constantly attempt to create teaching situations in which the subject material appears in a fresh context with new meaning. They know this is the way to fix concepts, to strengthen and broaden concepts, or to bring about the formation of modified or new concepts. They know that the meaning of a concept increases when it is examined in varied new contexts. In this way they build in depth and produce a more profound scholarship than if the concept were based upon only one set of facts. To illustrate:

In the elementary school a youngster may learn that green plants do not grow well in the dark, that they mature only in light. In the seventh grade, there may be a demonstration and discussion to show that green plants make starch in light. In the ninth grade, reconsideration may show that oxygen is a by-product of the starch-making. The teacher may even develop the idea that

TABLE 15-5 A course in earth science

I. The earth's surface
  A. The earth's crust
    1. Mantle rock and bedrock
    2. Land forms
    3. Minerals
    4. Rocks
  B. The waters of the earth
    1. The oceans
    2. Ground water
  C. Using maps
    1. Map projections
    2. Topographic maps

II. Destructive forces
  A. Weathering
    1. Mechanical
    2. Chemical
    3. Factors influencing weathering
    4. Results of weathering
  B. Erosion
    1. Action of ground water
    2. Action of running water
    3. Action of moving air
    4. Action of moving ice
    5. Action of waves and shore currents

III. Constructive forces
  A. Diastrophism
    1. Earth movements
    2. Major land forms
  B. Vulcanism
    1. Extrusive vulcanism
    2. Intrusive vulcanism
  C. Outstanding physiographic features
    1. Of New York State
    2. Of some of the national parks

IV. The age of the earth
  A. The rock record
    1. Crustal processes
    2. Rock sequence
    3. Fossil content
    4. Radioactive minerals
  B. The earth's history (over three billion years' duration)
    1. The earth's beginning
    2. Geologic history (over two billion years' duration)

V. The earth in space
  A. The earth as a planet
    1. Characteristics of the earth
    2. Planetary motions
    3. Time
    4. Location
  B. Stars and galaxies
    1. The sun and stars
    2. The galaxies

VI. Local weather changes
  A. Temperature of the air
    1. Insolation
    2. Transfer of energy
  B. Pressure of the air
    1. Weight of air
    2. Factors affecting pressure changes
    3. Pressure changes and local weather
  C. Local winds
    1. Origin
    2. Effect of rotation
    3. Measurement
    4. Wind direction and weather
  D. Moisture in the air
    1. Evaporation
    2. Condensation and precipitation

VII. Air masses and fronts
  A. Structure of the atmosphere
    1. Composition
    2. Extent
  B. Atmospheric circulation
    1. Planetary winds
    2. Special winds
  C. Movement of air masses
    1. Air masses
    2. Development of fronts
  D. Cyclones and anticyclones
    1. Origins
    2. Storms
  E. The weather bureau
    1. The weather map
    2. Weather forecasting services
    3. Value of weather services
  F. Climate
    1. Climatic controls
    2. Climates of the world

15-8. In some junior high schools a core program involves English and social studies while science and mathematics are taught separately. What values and what deficiencies can you see in such an arrangement?

15-9. What characteristics should a teacher of science have to work happily and effectively (a) In a "child-centered core program"? (b) In a school having a core program in English and social studies?

General Science Equipment Inventory. A complete check list of supplies and equipment organized to facilitate ordering and making the annual inventory

Source Book of Test Items for Teachers of General Science. A collection of short answer test items for each of the ten areas outlined in the syllabus.

Planning Science Facilities for Central Schools. Specifications for science rooms including furniture, equipment, storage space, and work space.

Film Round-Up No. 16, General Science. A list of carefully selected films organized under each of the 10 syllabus areas.

15-2. How much science do your students know? How much have they learned in the elementary school? Have you administered some of the standard tests listed on pp. 432-33 in Chapter 20?

15-3. Have you copies of the courses of study developed in general science by teachers in various cities? Write to the Director of Instruction, City Board of Education. (See the "Excursion" at the end of Chapter 12 for information on where to get curriculum materials)

Have you copies of ten or more recent texts, and their accompanying workbooks?

Have you recently observed other teachers of general science at work in their own classrooms?

15-4. Now examine the course in earth science shown in Table 15 5. Assume that it is being considered by teachers to replace general science in the ninth grade, in various situations:

(a) Where the previous general science and elementary science experience is, in your estimation, "poor." What areas of experience would the children have missed? List not only subject matter areas but skills, attitudes.

(b) Where prior general science (grades 7 and 8) and elementary science experience is "excellent." Again, in your estimation, what advantages or disadvantages would be introduced by the substitution of this course for general science in the ninth year?

(c) It has been suggested that earth science be taught pervasively throughout the science curriculum, even as conservation is. What advantages do you see to its inclusion in elementary science, general science, biology, chemistry, and physics? What disadvantages?

15-5. Examine general science texts which represent curricular organizations of types 1, 2, and 3 (see p. 319). Compare their selection of materials, emphasis, appeal to the interests of children, depth and range of concepts.

15-6. If you were teaching a "child-centered course" of type 4, how would you use the available general science texts?

15-7. For some topic which you know well, compare the subject material proposed in texts organized according to types 2 and 3.

seems to be a growing belief that a physical science course might serve the aims of general education (as developed by the Harvard Report and other publications) better than would separate courses in physics and chemistry. This seemed to be the base for the origin of the biology course which replaced separate botany and zoology courses (Chapter 12); and perhaps the integration of the physical sciences will follow somewhat the pattern of the earlier amalgamation of the biological sciences.

Still further, colleges generally accept the course for admission. Carleton [5] found that among 95 colleges, none were unwilling to approve it.

Tentative patterns of courses in physical science

The trend toward the physical science course—if indeed it proves to be a trend—is too recent, too experimental for us to discuss it as fully as we have the older, more established courses. We shall simply make two general comments and then present in tabular form, without comment, five course outlines that seem as typical as is yet possible.

First, the course has not yet "sought its own level." It is presented in various grades and aimed at various types of students. For example:

1. Physical science in the eleventh grade, followed by physics or chemistry or a term of each in the twelfth grade.
2. A two-year course, substituting for physics and chemistry.
3. A ninth-grade course for the science prone.
4. A general education course, for noncollege-destined students, in the tenth, eleventh, or twelfth grades.

Second, the course varies in its approach to the laboratory from a demonstration-lecture course to a course in which full laboratory work (as in chemistry or physics) is offered.

Tables 16-1 through 16-5 present brief outlines of some existing courses.

TABLE 16-1 *A tenth-grade course in physical science* *

I. Introduction (2 weeks)

II. Solar system (3 weeks)

III. States of matter (2 weeks)

IV. Energy (2 weeks)

V. Physics (15 weeks)
   - A. Forces
   - B. Force and motion
   - C. Work, energy, and power
   - D. Sound
   - E. Light
   - F. Electricity

VI. Chemistry (12 weeks)
   - A. Chemical change
   - B. Nature of chemical processes
   - C. Solutions
   - D. Nonmetals and compounds
   - E. Organic chemistry
   - F. Useful metals

* Nelson L. Lowry, "Biology and Physical Science for Ninth- and Tenth-Grade Students," *Science Education*, Vol. 35, March 1951, pp. 71-73

[5] Robert H. Carleton, "The Acceptability of Physical Sciences as a College Entrance Unit," *Science Education*, Vol. 30, Apr. 1946, pp. 127-32.

CHAPTER 16

Inventions in science courses:

The course in physical science

A note at the beginning: As general science is derived from geology, biology, chemistry, and physics, so physical science seems to be derived from geology, physics, and chemistry; it might be described as science minus biology.

War changes many things. Just prior to World War II, Watson[1] reported that physical science courses were offered in 54 cities of over 25,000 population located in 26 different states. During the war the course virtually disappeared; it was replaced by special courses, the so-called "war courses." A study by Johnson[2] in 1947-48 of a stratified random sample of 755 public high schools listed only seven schools giving courses in physical science.

And now? There are indications that the course is coming back, although it is too early to make any definite predictions as to the form it will take or even the success it will have. Carleton, who has done major work in this area, believes that this is so.[3] Let us look briefly into some of the reasons why this might indeed be so, and then examine the various tentative directions the course seems to be taking.

Bases for a course in physical science

The Harvard Report, *General Education in a Free Society*,[4] develops the point that "Science instruction should be characterized by broad integrative elements," and further it recommends that such a course give "a systematic presentation of concepts of the principles of the physical sciences." There

[1] Donald R. Watson, "A Comparison of the Growth of Survey Courses in Physical Science in High Schools and in Colleges," *Science Education*, Vol 24, Jan. 1940, pp. 14-20.

[2] Philip G. Johnson, *The Teaching of Science in Public High Schools*, U. S. Office of Education Bulletin No. 9, Washington, D. C., 1950.

[3] Robert H. Carleton, "The Course in Physical Science," in the National Society for the Study of Education, *Forty-Sixth Yearbook*, Part 1, *Science Education in American Schools*, U. of Chicago Press, Chicago, 1946.

[4] Harvard U. Press, Cambridge, 1945.

TABLE 16-5 ***A two-year course in physical science in a private school (with comments by its originator)*** *

I. First year
  A. Heat
  B. Hydrogen
  C. Oxygen
  D. Water
  E. Carbon and its compounds
  F. Chemical problems on weights and volume
  G. *Machines*
  H. Hydrostatics
  I. Light

II. Second year
  A. Electricity
  B. Chemistry [further]
  C. Mechanics
  D Atomic energy

* "The immediate problem was to devise a suitable course (a two year sequence) beginning in the tenth grade that would lead to advanced work in the twelfth grade. The usual one-year courses in physics and chemistry (the so-called College Board courses) were already offered. But these for obvious reasons were unsuitable—the physics course assumed more mathematics than was offered in the tenth grade; the chemistry course included many concepts which, unless bolstered by physics, would be largely unintelligible at this early stage. The obvious compromise was to draw up a syllabus which included both physics and chemistry, but planned in such a way that the physics would not get beyond the range of the advancing mathematics, and the chemistry would derive the maximum benefit from the physics. Thus a physics-chemistry course (a two year sequence) was established. . . .

"There are several reasons why Heat is a good starting subject for this course. The various topics in elementary Heat are uncomplicated—they can be understood without too much dependence on physical concepts from other fields. Moreover, the mathematics involved is simple, usually not beyond the range of tenth-grade students, many of the ideas have a direct bearing on the elementary chemistry which follows, particularly concerning heats of reactions and the heat values of fuels." (John C. Hogg, "Science at Exeter," *New England Association Review* 6, 1, Nov. 1957, p. 16.)

A look at the future of the course in physical science

It seems apparent that the course in physical science is again gaining attention, particularly as the high school accepts all the students with their great variety of gifts and circumstances and opportunities. Brown,* in a definitive article written in 1953, cites the following as a kind of summing up of the status of the physical science course.

1. The physical sciences are yielding. There is a shift in emphasis from concern for subject matter to concern for the learner. [Note: Is this true now?]

2. There is no clear-cut pattern for these courses and little evidence of an integrating theme, although there is general agreement on the desirability of integration.

3. The proper role of the textbook is not clear. Possibly an entirely new concept in textbook design is needed.

4. There is uncertainty concerning laboratory work. There is agreement on the desirability of providing the opportunity for individual and group activities. How to adapt the laboratory of conventional chemistry and physics to more functional purposes *is the problem. New kinds of laboratory experiences* may well be needed.

* H. Emmet Brown, "Trends in High School Courses in Integrated Physical Science," *National Association of Secondary-School Principals Bulletin, 37, p. 85, 1953.*

TABLE 16-2 A "practical" course in physical science *

1. Introduction
2. How can comfort be increased by air conditioning?
3. How does science improve our homes and office buildings?
4. How does water control our way of living?
5. What should we look for when buying an automobile?
6. How do we obtain our gasoline?
7. Do we obtain food and poison from the same molecules?
8. Will plastics and the new synthetic textiles make nations independent?
9. How do we obtain the most valuable metals?
10. What's wrong with this picture?
11. What has science done for communication?
12. What is there left to invent and discover?

* Shailer Peterson, "The Evaluation of a One-Year Course, the Fusion of Physics and Chemistry, with Other Physical Science Courses," *Science Education*, Vol. 29, Dec. 1945, pp. 255-64.

TABLE 16-3 A "functional" course in physical science *

I. Meteorology, earth science, and astronomy
   A. The weather
   B. The air
   C. Water
   D. The earth
   E. The heavens

II. Communication and transportation
   A. Communication
   B. Transportation
   C. Fuels

III. Materials and processes
   A. Metals, building materials, and glass
   B. Chemical products
   C. Fabrics

IV. The home
   A. General
   B. Personal

V. Orientation
   A. Men of science
   B. Work and leisure

* M. E. Herriott, and Charles H. Nettels, "Functional Physical Science," *Curriculum Journal*, Apr. 1944, pp. 362-65.

TABLE 16-4 An intermediate-level course in physical science *

1. The earth in space
2. Atomic structure of matter
3. Combinations of atoms
4. Atomic energy
5. Work and machines
6. Heat
7. Electricity
8. Light
9. Communications

* From a West Coast school. The course is of the same order of difficulty as the "average" biology course, and is intended for students who are not science prone, but may or may not be college bound. Standard geology, chemistry, and physics texts are used.

CHAPTER 17

Inventions in science courses:

The unit in the course

A note at the beginning: When a student says "I know that the earth is round," or "I know how plants make starch," or "I know the name of my teacher," what does he mean? The verb "to know" in English serves a dual purpose: it can mean *to recognize* (be aware of or familiar with) and it can also mean *to understand* (comprehend, make a part of oneself). Most languages employ two different verbs (French, *connaître* and *savoir*, German, *kennen* and *wissen;* Spanish, *conocer* and *saber*) for these two very different meanings. We use one for both Therefore, we must be very careful that recognition does not pass for understanding. We must teach, and plan to teach, specifically for understanding. We do this in planning the lesson (see Chapter 7); we do this in planning the course (see Chapters 10 through 16, and 18); but we do this to best effect in planning the unit.

As a basic proposition we must observe that everything learned in school *could* be learned outside of school. But there is no need for students to learn everything through the "school of hard knocks" or in isolation on their own. What then is the purpose of a school other than *to expedite* learning (which it does through careful selection of materials)? This forces the question: What learnings, both recognition and understanding, do we wish or can we expedite in school? As a corollary, how will our instruction most effectively expedite these learnings and how can we tell that such learnings have occurred?

Irrespective of the particular answers made to these questions, planning for instruction is essential. This includes planning for the daily lesson (Chapter 7) and planning for the thirteen-year sequence from kindergarten to high school graduation. It also includes planning a block of learning in between these in size: the unit.

5. There is general agreement on the use of field trips and for making use of all kinds of resources. The problem is to find the time.

6. Courses have been developed by teachers on their own time, although county and local workshops are being used to help in some places.

7. The teacher is still the "key" figure; some approach the idea with enthusiasm but some seem overwhelmed by the idea.

8. Present teacher training programs fail to produce the kind of teacher needed. Inservice education is important.

9. Units or areas are generally regarded as resources or guides rather than as inflexible blueprints.

10. Many modern courses in physical science have been approved for college entrance credit.

11. Pupil planning should play a large part in the flexible class procedure suggested in No. 9 above.

12. Integrated physical science courses are probably as well suited as the basis for further college work as are existing special courses.

13. As a terminal course, a physical science course may be superior to special courses.

14. Careful consideration should be given to the contributions of the expanding program of elementary science in planning physical science courses.

15. Studies should be made of the results of instruction in physical science courses, and of claims for these courses such as suggested in Nos. 12 and 13 above.

A brief excursion into developing a course in physical science

For those teachers who want to develop their own courses in physical science, we recommend not only an examination of the present texts in physical science (although a combination of texts might be used), but also the following papers:

Miles, Vaden L., "A Determination of Principles and Experiments for an Integrated Course in Physical Science for High School," *Science Education*, Vol. 33, March and April 1949, pp. 147-52, pp. 198-205.

Physical Science Symposium, "Physical Science Today," *Science Teacher*, Vol. 18, Nov. 1951, pp. 13-21.

Robinson, Myra G., "The Contributions of a Fused Science Course to General Education," *School Review*, April 1946, pp. 215-21.

Tenney, Asa C., "A Fused Physical Science Course," in the Report of the Committee on the Function of Science in General Education, *Science in General Education*, N. Y.: D. Appleton-Century, 1938, pp. 477-500.

citing work of others, being honest about the data, and in the social domain considering the proper role of scientists in the society, as well as the ways by which the results of scientific work are applied through technology. Thus, units are likely to include all three aspects, but one or another may be emphasized.[3]

> The teacher who is conscious of the ultimate goal—integration within the learner—will therefore plan all units toward that end. All units will deal with subject matter and materials, with processes of study and thought, combined in experiences best suited to the ultimate and immediate goals. The *difference between units which are basically alike* will be in the *emphasis* put on subject matter . . . on the one hand, and upon processes of problem solving, generalizing, critical evaluation, and other patterns of study and reflective thought on the other hand
>
> The key to the varying emphasis lies in the level of maturity, the experiential background, the purposes, needs and interests of the learner. These factors inescapably determine which experiences will be educative, that is, will enhance the integrating growth of the learner.

Building a unit

Many formats for arranging units have been proposed. Surely, there is no magic in how the teacher's plan is put on paper; no format is sacred. Yet certain questions are critical in the planning, and should be forced continuously upon the teacher as the plan is developed. Among such questions are these:

1. Why will the pupils be interested in the unit? In its parts? Without involvement of the pupils, the teacher will be pushing a large dead weight which will drag, buckle, or stray during the class sessions. Therefore, how does the teacher involve the students so that the study utilizes their enthusiasm and energy?

2. What evidence can be presented firsthand or vicariously which will stimulate the formation of new, larger concepts than the students had formerly? Especially in science we constantly appeal to the "stubborn, irreducible facts" to determine whether our ideas provide useful predictions. The availability of evidence through laboratory work, demonstrations, field trips, films, reading may limit or broaden what we can accomplish through the unit.

3. How can we determine the success of our instruction? What observable behaviors will the students exhibit that reveal learning? Unless we continually check upon how well we are progressing, the class operation may dissolve into aimless activity without approaching the objectives intended.

4. But of greatest importance are the teacher's objectives. Since we are viewing science as an intellectual activity, such objectives take two parallel forms:

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[3] Burton, *op. cit.*, pp. 393 94.

The purposes of units

A unit is a planned block of study unified by those major concepts whose comprehension involves certain skills and abilities. The plan of a unit for class use is based on an awareness of the importance of the major ideas and the realization that they can have no meaning to the learner if they hang in mid air as verbal statements without roots in experience. The teacher's central task in designing a unit is the isolation of large ideas or concepts to be comprehended and significant abilities to be developed by selected experiences.

In many ways a unit plan is similar to a legal brief. It is a clear statement of the intent of the argument and the evidence, as well as the precedents (established concepts) which will support the argument and the conclusion. Such a brief is prepared by both counsels and submitted to the judge before the case opens. This allows the judge to consider the niceties of the legal distinctions to be made and to check on the previous decisions used as precedents. In school such a unit plan might be discussed with other teachers in advance of use for their advice and further suggestions. As is quite apparent, the legal argument submitted to the judge does not determine the way in which the lawyers will present the case in court. They may begin in the middle or at the end of their brief. They may introduce histrionics, pathos, suspense, surprise in their effort to convince the jury. Similarly the teacher may operate the class in many ways to achieve the ends clearly diagnosed in the unit plan.

Effective unit design necessitates viewing learning as dynamic. All types of learning are occurring *simultaneously*. Factual information, concept modification, skills and abilities, attitudes grow together, not one at a time. The unit is a plan by which we attempt to provide a rich and diversified "experience in search of meaning."

The initial definition of a unit and its potentialities for evoking understanding rather than mere recall were stated in 1926 by Morrison. Since then there have been many labels given to units: subject matter units, topical units, experience units, and so forth. Gradually, the possible variety of units was reduced, until in 1945 Smith[1] concluded that the primary intentions of units might be:

1. Process units: units of discovery and verification.
2. Normative units: units establishing policies
3. Critical units: units establishing critical skills and abilities.

Burton[2] observed in 1952 that these aspects necessarily appear in all units, but with varying degrees of emphasis. If we looked at Smith's three types of units, we would probably feel that most of those in science would be "process units." But surely we are concerned with establishing critical skills and abilities. And often we are concerned with establishing policies: properly

[1] B. Othanel Smith, "The Normative Unit," *Teachers College Record*, 46, 219, 1945.
[2] W. H. Burton, *The Guidance of Learning Activities*, 2nd ed., Appleton-Century Crofts, N. Y., 1952, p. 393.

taneously, and the format of the unit serves a very useful purpose when it makes this clear.

More recent unit plans have indicated an awareness of this simultaneous development by arranging the objectives, activities, evaluation ideas, and even the bibliography in parallel columns. But no published plan which we have seen includes all these factors. Therefore, a new design is presented here (Table 17-1); perhaps it may be useful.

So far, our discussion has included the components which are essential to the practicing teacher. But others, school administrators, parents, are also interested in the essential purposes of the planned instruction. Therefore, a brief preamble, or "overview," which explicitly describes the relation of this unit to the general goals of the total school program, is often desirable. Another prefatory section might indicate several possible means by which the attention of the students could be focused on the unit.

Teacher objectives should be terse and clear. These are statements of concepts to be built through the students' activities. Unless the concepts are clear, you will not know where you or the students are headed. Burton has recommended the form: "Understanding that—." Grammatically this must be followed by a complete and explicit statement. A common alternative is "An understanding of—," but where does this lead us? Generally, we will find something like this. "An understanding *of* the relation between a plant and its environment." Or a statement like this: "An understanding *of* the five simple machines." What relation? What understanding? No other teacher can tell what is sought, and even the user of such a unit cannot tell when he has accomplished his purpose. Class time is brief, and our responsibilities are many; we must be explicit so we can tell when we have been successful. The form in which we present our unit plan can serve to force us to ask the necessary questions and keep our purposes as teachers always before us.

TABLE 17-1 (cont.)

Pupils' objectives	*Evidence*	*Equipment and supplies*	*References*
Anticipated questions like: How? When? How much? What happens if . . . ? What is the relation between . . . ? What has this got to do with me?	*Direct* experience to gain answers to their questions in: Classroom Community Field trips *Vicarious* experience through: Films Filmstrips Recordings Hearing speakers	Specific things needed for the particular activities listed: Equipment Supplies Films Filmstrips	Relevant reading materials, specific references to: Books Journals Periodicals Pamphlets Encyclopedias

a. What large concepts are sought?

b What aspects of scientific inquiry can be illustrated through the development of the new or enlarged concepts?

We might describe these two types of objectives as the *products* of science and the *process* of science Of the two the process is of greater importance, for it will be available to use on new problems yet unknown to the students. However, without some products to build upon, no process can be practiced or illustrated. The two are as interdependent as a refining plant and the raw materials to be refined.

The function of format

Now the function of the format used appears; its purpose is to keep before the teacher the several questions which must be considered simultaneously In many units published some years ago the various questions were considered sequentially down the page. First came the teacher's objectives, often in considerable detail. Then, below, usually came a series of interesting activities in the form of experiments, field trips, demonstrations, and such. Below that came some evaluation possibilities and then probably a bibliography that might be useful. What was likely to happen is clear: The objectives were glanced through, the activities were considered as the "meat" of the unit, and evaluation was postponed to that dreadful moment at the end when something had to be done about grades. Actually all these aspects of teaching go on simul-

TABLE 17-1 A suggested format for unit planning

1. *To administrators and parents: how unit would be of use to pupils; types of learnings pupils would gain from it.*
2. *Large objectives to be stressed, how related to larger objectives of course and total program.*
3. *Various initial means of focusing pupil interest on the unit.*

TEACHER'S OBJECTIVES		
Process of scientific inquiry, pervasive objectives	*Results of scientific inquiry, limited objectives*	*Behavioral objectives, evaluation*
How do we know? How well do we know? How do we make sense out of observable phenomena? How can we study things and events we cannot see? What kind of sense do we make from our observations? What are the consequences of the sense we make?	What regularities, patterns, generalizations, laws, etc., can we find among specific observable phenomena? Where are these regularities applicable? Where are these regularities *not* applicable? What degree of security do we have in using these regularities in predicting new results?	What does the student *do* that indicates he has accomplished the learning intended Predictions Demonstrations Reading Criticism Projects

illustrated and practiced through this study. First, there is a need for classification in both kind and amount. We would need to isolate the factors probably influencing the growth of a plant. Many of these, like rainfall and temperature, are expressed in numerical form, so "how much?" becomes important. Graphs might be desirable. Many predictions would be made and checked by observations. The peculiar nature of negative evidence ("we expected lady-slippers but found none") would have to be considered. The importance of *time* for experimental studies in biology would be obvious. Likewise, the myriad of specific observations necessary in any study could not be avoided. Efforts to group and describe the environment according to certain not-obvious attributes like soil acidity would be necessary. A much larger list could be continued from here.

What supporting materials might be used? A great variety of periodicals on farming, gardening, and forestry could be used. The Yearbooks of the U. S. Department of Agriculture would be very helpful. Texts on biology and botany should be at hand. And special attention should be given by the teacher during the planning to two excellent publications: *Handbook for Teaching of Conservation and Resource-Use*[4] prepared for the National Association of Biology Teachers, and *Conservation Education in American Schools*,[5] prepared for the American Association of School Administrators. Both of these books have many references and suggested activities. In addition, considerable useful material can be obtained from various industries concerned with farming, baking, and nutrition.

A unit on this topic could tie in, before or after, with a study of geology and the formation of soil, with a discussion of evolution; with wise land-usage and conservation; with meteorology; with nutrition; with practical gardening, and local town and school beautification; with the dependence of all animal life upon plant life. Any study in science has so many contacts with other general topics that coherence within a course is easily obtained. The teacher need only scout the possible leads in advance, and emphasize those leads when they appear during the unit to set up the extension of this study through the next unit.

The previous knowledge and concepts of the students, their readiness, is now put to work. Recall is necessary, and personal review is probably desirable to clarify points that now take on new significance. The opportunities for work at different levels of ability are obvious. So is the involvement of many skills in gathering information and organizing it in compact form (charts, dioramas, models, garden plans, model farm plans, reports on local areas, etc.). Each such activity, in which the student feels a personal pride and responsibility, encourages him to seek out ever more information, so that his final report will be as accurate and comprehensive as possible.

Now the material above is *not* a unit. It is only the first exploration of

[4] Richard L. Weaver, Interstate Printers and Publishers, Danville, Ill., 1955.

[5] American Association of School Administrators, *Twenty-Ninth Yearbook, Conservation Education in American Schools*, NEA, 1951.

An approach to a unit on plants and their environment

Consider now what changes occur if we restate the first example above in the form "Understanding that——." We come to something like this: "Understanding *that* the growth of a plant is intimately related to its immediate environment." Now what do the words mean? We can accept common experience as providing a starting point for what is meant by "growth" and "plant." But how about "intimately related" (in what ways?) and "immediate environment" (how immediate, what aspects?)? Our format has led us to a series of subquestions whose answers are the building blocks upon which the larger concept rests. Some of the subconcepts might involve investigation of:

Importance of rainfall: average, maximum, minimum, annual distribution, flooding.

Temperature and its range: average, maximum, minimum, where measured, period above some minimum for plant reproduction, life-cycle of arctic plants.

Sunlight: amount, annual variation, local shade.

Soil composition, texture, acidity, mineral abundance, water table, and plant root depth (desert plants).

Presence of predators: insects, mollusks, animals.

Characteristics of plants generally found together.

How man's activities disrupt the environment.

To reach any type of valid (trustworthy) generalizations about the significance of these and other factors, the best (how do you know it is "best"?) growing conditions for many different plants would need to be defined. This might take the form of "one plant—one student" after the list of important factors has been started cooperatively. Since additional factors would be discovered during the investigation, the initial list need not be all-inclusive.

How might the data be obtained? Partly, surely, through direct experimentation, but this would require time for the plants to grow enough, and appropriate heating and soil conditions. Films might add certain information and evidence of how plants grow. Field trips to a forest, a pond or marsh, the seashore, a meadow, the desert—whatever is at hand—would put the study on solid ground. A greenhouse, either commercial or private, offers many possibilities. Speakers such as a nurseryman, an experienced flower gardener (perhaps a parent of one of the students), or a forest ranger could be helpful. The possibilities are numerous, depending upon the community. In a large city the pattern would differ from that in a suburban or a country school.

There is no need to point out how this study would demand information and concepts from many areas of science. These would not necessarily be "taught," but rather "used." The children would have some previous knowledge about each area and would find that knowledge useful in this new investigation. Thus one encourages review and adds meaning to former studies.

Perhaps we should consider what aspects of scientific process might be

illustrated and practiced through this study. First, there is a need for classification in both kind and amount. We would need to isolate the factors probably influencing the growth of a plant. Many of these, like rainfall and temperature, are expressed in numerical form, so "how much?" becomes important. Graphs might be desirable. Many predictions would be made and checked by observations. The peculiar nature of negative evidence ("we expected lady-slippers but found none") would have to be considered. The importance of *time* for experimental studies in biology would be obvious. Likewise, the myriad of specific observations necessary in any study could not be avoided. Efforts to group and describe the environment according to certain not-obvious attributes like soil acidity would be necessary. A much larger list could be continued from here.

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what might go into a unit and how it might be a useful teaching device. We have not considered how the students might be interested in this topic, but a variety of possibilities based on the local environment come to mind.

One major point about such planning must be emphasized. *It does not determine or restrict the classroom procedures of the teacher.* What we have done is to make an intellectual reconnaissance of the potentialities of a topic, to see what it might contain in terms of information, concepts, and student involvement. This would be done irrespective of the manner in which the material was considered in class. A college professor lecturing to a thousand students at a time would have examined the possibilities in much this way. How he might present the evidence at firsthand, of course, would differ from the possibilities available to a teacher with a small class adjacent to a park or a wooded area or even a well planted school yard.

At least two criteria will influence the decision as to whether or not this material is ever used in class. First, the local facilities, the "hardware" of instruction or, better, "the evidence," may not be adequate for the proposed study. Either more must be obtained or some other topic used instead. Second, the particular ideas to be developed and the examples of how the scientist works may require such a wealth of preparatory detail that the time could be spent more profitably with other material. (An example of this occurred in one of the general education courses in science at Harvard. A total of six weeks had been allocated for the consideration of certain simple aspects of Newtonian physics and the predictive power provided by these generalizations. Despite 18 lectures and six discussion sections, all with numerous demonstrations, the staff concluded that the students had been lost in a morass of technical details and never saw the importance of the generalizations reached. The next year a shift was made to selected material dealing with the nature of electrical charge; this appeared to be more readily grasped by the students) In the initial design of a course, many promising possibilities must be explored and matched against the time available and the abilities of the particular students; more than half the possibilities explored will be laid aside as probably impractical.

An approach to a unit on sound and music

In these days of high fidelity, ultrasonics, sonar, sound insulation, and generally poor acoustics in auditoriums, a unit on sound, music, and hearing might be quite useful in a science program. Let us explore the possibilities. Where should we start? With the students' interests, the teacher's objectives, observable behaviors? It does not really matter. Mulling over any general topic such as this will suggest a variety of possibilities, each of which must be explored further in terms of the instructional "payoff" that might be obtained

What makes a high fidelity set "high"? Most pupils have such sets available to them or read of them in widespread periodicals. One company adver-

tises "distortion free to 20,000 cycles"; what does this mean? Can these upper frequencies be heard? If so, does their absence make a significant difference in the quality of sound heard? What is a woofer? A tweeter? Why is a 33⅓ rpm record "long-playing"? Can records be made which are still longer-playing? What is a bass-reflex speaker cabinet and why is it recommended?

How can bacteria be killed by "just a sound wave"? Are there sounds we cannot hear? How do birds, insects, and mammals communicate? Do fish make noises? How does sonar work? If you were at sea 50 miles from a hydrogen bomb blast on a small island, what would you expect to observe?

Why, sometimes, do we hear a throbbing from the engines of a multi-engined aircraft? How is a piano tuned? Why do school orchestras often sound so off tune? Why do a flute, violin, and clarinet, all sounding the same note, sound different? How is a violin tuned? How is a trumpet tuned? Can I make a musical instrument that really plays?

Why can't we hear well under the balcony in our school auditorium? Why does music sound so different when the auditorium is empty during practice compared to when there are many people in the audience?

How can geologists study the inner parts of the earth or determine the thickness of the ice cap in Antarctica? How can oil men tell where to drill?

How can we get answers to all these questions?

Possibly the teacher would begin with certain major concepts as his objectives. Alongside would then be listed some of the behaviors which would indicate the understanding sought (see Table 17-2). The list in Table 17-2 can, of course, be extended with many additional specific objectives. As we are not attempting to create an exemplary unit, but only to indicate how units can be shaped, we shall end the list and restructure the items cited. What is now needed is the working part of the unit, the listing of evidence that the students would need to convince themselves of the understandings listed. Also, we must indicate the materials necessary for providing this evidence, both "hardware" and reading matesials. In this partirular subject, most of the phenomena can be experienced at firsthand by the student so that reading is mostly supplementary, except for large scale applications (seismology) or special devices (sonar). We shall indicate some possible experiences, but each teacher will see others that could be added to the list. What will be done in a particular classroom will necessarily depend upon both the materials immediately available to the teacher, and his own preferences.

As we illustrate an approach to the formation of a unit plan, one point is surely clear: cooperative planning among a group of teachers (not only from the subject area involved) will provide a richer set of ideas and experience than a single teacher would readily see.

In the design presented in Table 17-3, we have included some pervasive objectives dealing either with how scientists operate or with the attitudes imposed upon the learner by the evidence at hand. The search for the limited understandings through the operations indicated would provide many oppor-

TABLE 17-2 ***Beginning of a unit plan on sound and music***

Teacher objectives	*Pupil behaviors*
The understanding that	
1 Sound travels only through a material, or medium	1 Predicts no sound on the airless moon, predicts no sound in a vacuum.
2 Sound travels at different speeds through different materials.	2 Predicts faster sound speed through water than through air; can interpret a seismogram; demonstrates how oil prospectors can locate salt domes, predicts "sound mirages" on foggy days.
3 Sound phenomena can be described by a wave model compression and rarefaction in a gas	3 Seeks a model to account for sound phenomena, can handle frequency-wave length problems, demonstrates nature of wave model, using "slinky" or other spring
4. Sound originates in a vibration.	4. Upon hearing a sound, searches for vibrating source; creates vibrating sound sources drum, string, reed.
5. Air columns can also vibrate	5 Can tune an "organ pipe" or bottle by changing length of air column; explains pitch changes of valved horn, slide whistle
6 Rapid vibrations are heard as high pitched sounds, slow vibrations as low pitched sounds	6 Predicts pitch from rate of vibration.
7. The human ear is insensitive to very low and very high frequencies	7 Suspects that animals (birds, insects, mammals) emit sounds we cannot hear, slows down record or tape recording to hear "inaudible" highest pitches
8. Musical sounds have periodicity or structure, while noise lacks structure	8 Uses oscilloscope to observe periodic pattern in musical sounds.
9. What is pleasing sound to one person may be unpleasant to another, musical tastes are highly influenced by the culture.	9 Is willing to listen to "odd" music, compares structure of modern music (Honegger, Piston) to Bach, Brahms, compares Western music to Oriental music (Indian, Chinese)
10 An object which will emit a given pitch will begin to vibrate ("sing") when exposed to sound of the same pitch (resonance)	10 Demonstrates this effect; searches for "bandwidth" of resonant effect with various objects, inquires about the structure of the inner ear, compares sound to radio reception.
11. Most vibrators emit a complex pattern of frequencies consisting of a fundamental and a blend of overtones	11. Uses oscilloscope to observe wave forms; predicts from mathematical analysis possible overtones; recognizes overtone pattern as providing timbre of tone
12 Sound waves are readily reflected from hard surfaces, but are absorbed by soft objects	12 Suggests draperies to lessen echoes in auditorium, predicts less echo when seats are occupied than when empty.

tunities for the development of the pervasive objectives. Yet these are often difficult to anticipate in detail. The teacher necessarily must "play by ear" as the investigation develops. This is where his comprehension of the nature of scientific work appears. If he is hurried and anxious to "put over" a large number of limited understandings closely tied to particular evidence, he can avoid the larger understandings. This unfortunately happens often. But the same topics and evidence, because they are part of science, contain examples of how scientists work. The pervasive objectives are right at hand in the material, if the teacher wants to see and develop them.

The design in Table 17-3 is not complete—purposely so. It is not meant to be adopted by any teacher. It is presented simply as a beginning, an approach, which may help teachers plan their own personal inventions in units.

Resource units

The type of unit we have been suggesting would probably be known as a resource unit. It is not intended for any one particular classroom. Rather it should contain so many possibilities that teachers in quite different localities, with quite different approaches, could select from it concepts and evidence appropriate to their intentions.

Any resource unit of this sort is only a means of clarifying the possibilities. It is not a rigid plan that must be followed in the classroom. In fact, quite the contrary is intended. By analyzing in advance the concepts that might be desired, the involvement of the students, and the materials that would be needed, the teacher is freed to focus his attention on the processes by which the students learn. There is no need to start at the "beginning" of the unit. Any question will provide a starting point from which the students will gradually discover that they need most of the concepts in the unit plan. Directed questioning, a novel demonstration, attention on explaining some overlooked phenomenon can extend the study until most of the understandings have been considered. The long-term plan is a basis from which the teacher can draw his daily lesson plans which take form as the investigation proceeds. We doubt that specific daily plans could or should be made far in advance, for this restricts the flexibility of the investigation.

Units in their context (their curricular environment)

Have you noticed that nowhere thus far have we commented upon the grade or even the course in which either of our sample units might be placed? This was deliberate.

Where do you believe a unit on plants and their environment would be most appropriate? If you have difficulties pinpointing its position in the curriculum, you begin to see that a subject area like this could readily be pervasive throughout the total curriculum. Certain introductory or simple aspects could be developed in the primary grades and extended in the intermediate grades. In the junior high years additional information and bigger concepts

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3 Sound phenomena can be described by a wave model compression and rarefaction in a gas	3. Seeks a model to account for sound phenomena, can handle frequency wave length problems; demonstrates nature of wave model, using "slinky" or other spring
4 Sound originates in a vibration	4 Upon hearing a sound, searches for vibrating source; creates vibrating sound sources drum, string, reed.
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11 Most vibrators emit a complex pattern of frequencies consisting of a fundamental and a blend of overtones	11. Uses oscilloscope to observe wave forms, predicts from mathematical analysis possible overtones; recognizes overtone pattern as providing timbre of tone
12. Sound waves are readily reflected from hard surfaces, but are absorbed by soft objects.	12. Suggests draperies to lessen echoes in auditorium; predicts less echo when seats are occupied than when empty.

Pupil objectives	*Evidence*	*Equipment*	*References*
1. What is a sound? What makes a rattle?	1. Assorted experience with sounds. Much may be drawn from previous experience.	1. Vibrating ruler, tuning forks, vocal cords, electric bell, pipes, yardstick, swimming pool (?), streetcar tracks.	1. Few needed, texts for further examples.
2. How does sound travel? Do fish hear our noises in a boat?	2. Sound signals through pipes, yardsticks, water, steel rails.	2. Vacuum chamber, bell, good pump.	2. Reading about moon and space flights.
3. Does sound travel at the same speed in all materials? How can we find out about the internal structure of the earth? How can oil deposits be located? Why, on a foggy day, is it so difficult to tell the direction from which a sound comes?	3. Same as above. Seismogram. Echo effects. Bending of sound direction by changes in atmospheric temperature and humidity. Films on oil-prospecting.	3. Seismogram. Large wall for echo experiments.	3. Material on seismograms, examples, and their interpretation. Material on oil-prospecting (oil companies?).
4. How can we make a picture of a sound? What is meant by frequency, by wave length?	4. Little or none. (This is an analysis based on evidence already acquired)	4. Long spring or a "slinky."	4. Text reading for reinforcement.
5. If something has to vibrate to cause a sound, how do we get a sound by blowing over an empty bottle?	5. Sound from "empty" bottle, organ pipe. Tuning by adding water to shorten length of air column.	5. Empty bottles of various sizes, organ pipe (?), tuning forks.	

TABLE 17-3 Partial unit plan on sound and music *

TEACHER'S OBJECTIVES		
Process of scientific inquiry, pervasive objectives	*Product of scientific inquiry, limited objectives*	*Behavioral objectives, evaluation*
1 Assumption of a cause for an effect	1 Sound originates from a vibrating body.	1. Upon hearing a sound, searches for vibrating source Creates vibrating sound sources drum, strings, reed
2 Limitations of the phenomenon.	2 Sound travels only through material: a medium.	2. Predicts no sound in a vacuum. Predicts no sound on the airless moon.
3. Further limitation of the phenomenon. Introduction of classification according to velocity. Application to new topics. Generalization from initial evidence.	3. The speed of sound is greater in liquids and solids than in gases, it differs with other properties of the medium.	3. Predicts faster speed of sound in water than in air Can interpret a seismogram Demonstrates how oil prospectors can locate salt domes. Predicts "sound mirages" on foggy days.
4 Search for a simple model of phenomenon Mathematical description possible Isolation of important attributes for model.	4 Sound phenomena can be described by a wave-model, compression rarefaction.	4. Handles frequency-wavelength problems. Demonstrates nature of wave model with analogue of long spring, "slinky."
5 Introduction of nonperceivable components, often necessary to unite varied observations	5 Air columns as well as solid objects can oscillate.	5. Can tune a "pipe organ," or bottle by changing length of air column Explains pitch of slide whistle, valved horns, trombone.

* Several important aspects of sound phenomena have been omitted, for example, interference phenomena and the creation of beats, the propagation of shear waves as well as compression waves in a solid, and the structure of the ear. The discrimination of intensities, or time differences, and pitch differences could also be developed

Pupil objectives	*Evidence*	*Equipment*	*References*
6 How can we tell what pitch we will get from a vibrator? How can we change the pitch?	6 Musical instruments, strings drums, horns, reeds, to be tuned. Examination of vibration pattern of single string varied in length and tension (weights)	6. Musical instruments of all types Single string with variable tension aod length (sonometer). String from hammer of electric bell.	6. Material on musical instruments, past and present.
7. What is high fidelity? Are there sounds we cannot hear? How do animals communicate?	7 Play variable frequency record 20,000 cycles down to, perhaps, 10 cycles Search for most sensitive range of frequency on ear Examine sound making and sound-receiving parts of other animals. Listen to bird call, fish noise, farm animal records.	7. Variable frequency record. Good quality phonograph. Records of insect, bird, fish, farm animal calls. Whistles or other sound sources of variable pitch. Dog whistle	7. Reading on high fidelity. Curves of human hearing limits. Material on animal communication, especially von Frisch on bees
8. What is the difference between a noise and music? Why do we like certain sounds and not others?	8. Observe musical tones on oscillograph, compare to noise.	8. Oscilloscope. Musical tone sources.	
9. Why does some music sound so odd? Why is Oriental music so different?	9 Search for pattern in chords and phrases of modern music. Compare to Bach, Brahms. Examine tones used (scale) of Oriental music.	9 Records and sheet music of modern composers and of Bach, Brahms. Record player. Records of Oriental music. Sheet music of Oriental music.	9. History of music. Assumptions of modern composers. Planned dissonance. Basis of diatonic scale. Possibilities of other scales.

TABLE 17-3 Partial unit plan on sound and music (cont.)

TEACHER'S OBJECTIVES		
Process of scientific inquiry, pervasive objectives	*Product of scientific inquiry, limited objectives*	*Behavioral objectives, evaluation*
6. Clarification and restriction of interrelations between variables considered important.	6. Pitch (vibrations per second) varies with many attributes of vibrator: size; length, size, and tension for strings.	6. Predicts pitch from rate of vibration. Realizes possibilities of "inaudible sounds"—ultrasonics. Expects large objects to emit low sounds, small objects to emit only high pitches. Predicts proper adjustment in tuning stringed instrument.
7. Recognized limits of human sensory mechanisms. Instruments are needed to explore where the human body is insensitive.	7. The human ear is sensitive only to a limited range of frequencies.	7. Suspects that other creatures emit sounds we cannot hear: birds, insects, whales, bats. Suspects that other creatures are insensitive to part of human sound range.
8. Aesthetic choice usually involves some pattern or structure.	8. Musical sounds have periodic structure while noise lacks such structure.	8. Uses oscilloscope to examine periodic pattern of musical sounds and of noise.
9. What is pleasing or satisfying to one person may not be so to another. Cultures differ in many respects.	9. Musical tastes vary between cultures.	9. Compares structure of modern music (Honegger, Piston) with Bach and Brahms. Compares Western and Oriental music.

Pupil objectives	*Evidence*	*Equipment*	*References*
6. How can we tell what pitch we will get from a vibrator? How can we change the pitch?	6. Musical instruments, strings, drums, horns, reeds, to be tuned. Examination of vibration pattern of single string varied in length and tension (weights)	6. Musical instruments of all types. Single string with variable tension and length (sonometer). String from hammer of electric bell.	6. Material on musical instruments, past and present.
7. What is high fidelity? Are there sounds we cannot hear? How do animals communicate?	7. Play variable-frequency record 20,000 cycles down to, perhaps, 10 cycles. Search for most sensitive range of frequency on ear. Examine sound-making and sound-receiving parts of other animals. Listen to bird call, fish noise, farm animal records.	7. Variable frequency record. Good quality phonograph. Records of insect, bird, fish, farm animal calls. Whistles or other sound sources of variable pitch. Dog whistle.	7. Reading on high fidelity. Curves of human hearing limits. Material on animal communication, especially von Frisch on bees.
8. What is the difference between a noise and music? Why do we like certain sounds and not others?	8. Observe musical tones on oscillograph, compare to noise.	8. Oscilloscope. Musical tone sources.	
9. Why does some music sound so odd? Why is Oriental music so different?	9. Search for pattern in chords and phrases of modern music. *Compare to Bach, Brahms.* Examine tones used (scale) of Oriental music.	9. Records and sheet music of modern composers and of Bach, Brahms. *Record player.* Records of Oriental music. Sheet music of Oriental music.	9. History of music. Assumptions of modern composers. *Planned dissonance.* Basis of diatonic scale. Possibilities of other scales.

TABLE 17-3 Partial unit plan on sound and music (cont.)

Teacher's objectives		
Process of scientific inquiry, pervasive objectives	*Product of scientific inquiry, limited objectives*	*Behavioral objectives, evaluation*
10. Concept of interaction, nicety of "fit" required. Beginning of "lock and key" concept	10. An object which will emit a particular tone will vibrate when exposed to that tone (frequency). Resonance (very important in terms of radio and spectral studies)	10. Demonstrates resonance. Explains "singing" of objects, rattling of auto windows at certain speeds, etc. Explores bandwidth of resonance effect. Inquires about structure of inner ear.
11. Many phenomena are more complex than they seemed at first. Mathematical patterns aid in making predictions. Instruments aid in making visible what was otherwise masked	11. Most vibrators emit a complex pattern of frequencies consisting of a fundamental and many overtones which have a particular relation to the fundamental frequency.	11. Uses oscilloscope to examine wave forms. Predicts from mathematical relationships what overtones are possible. Recognizes overtone pattern as providing "quality" or timbre of tone.
12. The solution of practical problems often demands a considerable theoretical explanation created through basic scientific investigation.	12. Sound waves are readily reflected from hard surfaces, but are absorbed by soft surfaces.	12. Suggests draperies to lessen echoes in auditorium. Recognizes importance of allowing for echo time in design of large rooms. Applies law of reflection in predicting echo strength and delay time. Designs house furnishings to lessen echoes.

Pupil objectives	*Evidence*	*Equipment*	*References*
10 What makes things "sing" or rattle? What is a sounding board or box for? Why should a speaker be in a big box?	10 Resonant tuning forks and resonant boxes. Fork in air and on hard table String in air and then over resonant box Radio speaker in air and attached to a sounding board. Tinny sound of small speaker with small resonating box. Musical glasses.	10. Resonant tuning forks and resonant boxes. Some way to "load" one fork to change its pitch slightly. String and resonant box. Radio speaker free of resonating box. Model of the ear. Musical glasses.	10. Material on natural period of vibration of buildings, ships, bridges. Material on the structure and care of the ear.
11. How can we tell the difference between two instruments sounding the same note? Does a vibrator have only one period? Why does an auto shake at certain speeds only?	11. With taut string, investigate variety of vibrations present. Note relations between overtones and fundamental. Define "octave." Define the diatonic scale.	11. Taut strings for small groups of students. Oscilloscope for examining wave patterns Sympathetic vibrators using overtones.	11. Explore the overtone patterns of various instruments.
12. Why does the school auditorium sound so empty? Why can we not hear well under the balcony? Why are some halls better for music or speaking than are others? How can we soundproof a house?	12 Exploration of the echo time and intensity in the school auditorium or gym. Examination of various soundproofing materials. Talk by an acoustical engineer or an architect. Experiments with draperies as sound traps. Calculations of the sound path in a large room Purpose of sound traps in newer auditoriums.	12. Drum for sharp sound, cymbals Soundproofing materials. Films on soundproofing	12. Reading on careers in acoustics and architecture. Magazine articles on soundproofing a home.

could be developed. In high school biology or chemistry a further extension could be made, and again in college and even graduate courses.

And what about the unit on sound and music? Is it suited for just one spot in the curriculum?

Units and grade level: vertical mobility

The moral is clear: An important subject is never exhausted no matter how many times it may be reconsidered. What does change is the complexity of the concepts and the wealth of information on which they rest. A fifth grade unit on conservation or ecology hardly exhausts the subject; it is barely a beginning, but satisfies the students at their level of knowledge. They outgrow this, and so further exploration is desirable. Even a high school unit only extends the students' concepts, but never "completes" a topic. Always additional possibilities for further study should be brought up, unanswered questions left dangling so that the student knows what he knows, and knows that there is yet more to be known. In this manner we avoid the banal statement, "Oh, we *had* that three years ago." The teaching and the planning before the teaching should point to this "open endedness" in scientific work.

And, of course, the readiness of a particular class must be considered. Several components of units like the one on sound and music are explored in the upper elementary schools; but the topic is hardly exhausted by this initial investigation; it is barely opened up. Teachers we know find that before the end of the ninth grade, most of the concepts indicated can be opened up with average children. Perhaps the physiological reception of sound could be extended more than we indicated, but some teachers would prefer to defer that as a component of biology. The more mathematical aspects of waves might be related to radio and light waves, and thus deferred to a physics course.

Units and course boundaries: horizontal mobility

Since there is only one world of reality, any topic within science will necessarily extend into many other subjects within the school curriculum. Teachers concerned with the total learning of their students will search for opportunities to interrelate science topics with the other subjects. How far they go depends upon their personal appraisal of their responsibilities as teachers. Some will talk with their fellow teachers about how their two courses relate and how learning and experiences in one field can be used in another.

In our example on sound and music, surely close ties with the music teachers would be desirable. The English teacher, interested in clarity of speech and diction, might have interesting suggestions to make. The social studies teacher, concerned about the impact of verbal communication upon people, might also have suggestions. (For example, in ancient Greece and on down in history through the Gettysburg Address, before the development of public address systems, only the audience within earshot of the speaker could

hear him. But public address systems and now radio and television have enormously increased the audience available to a speaker or performer.) The mathematics teacher might welcome some opportunities to encourage practice on simple time-distance problems, ratios or proportions, graphs, and scales.

One logical end of such correlation, obviously, is a core approach (see p. 378). Unfortunately, there are very few examples of core units which include science. Generally, the core program in the junior high grades combines English and social studies, but omits mathematics and science. These are "special subjects" taught with their own internal structure. Whether embracing core units will become popular within the secondary school, we do not know. As we indicated earlier, unusually well-informed and able teachers are needed if a core including all subjects is to be even contemplated.

But there are many stages of correlation short of the core. And a certain amount of correlation is bound to take place in the students' minds; it will probably be more successful if the teacher guides the process. After all, our concern as teachers is to help boys and girls become integrated persons, with themselves, with others, with the world around them.

A bibliographical excursion into developing one's own units

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selves with these phases; we do this by citing examples of policy and process in curriculum revision.

Research as a frame of reference

In Chapter 21, Appraising the Teacher's Role: Supply and Demand in Science, we indicate that science teaching as a whole has been "successful"; that is, if we view the entire enterprise. In the same chapter, however, we indicate that although valid and reliable data in science education are limited, still, such data as are available support the working hypothesis that Burnett states.[1]

> Studies related to college preparation seem to support the hypothesis that increased power of analysis, ability in critical reading and thinking, and independent and reflective thinking are more important than the acquisition of facts for success in college. Studies of the retention of science learnings, generally limited to the retention of specific facts and skills typically tested for on standard examinations, appear to indicate that students, in the physical sciences at least, do not retain their subject-matter knowledge well. This low retention on standard examinations may reflect an even lower retention of knowledge that will function in nonacademic situations. Various studies have shown that conventional science teaching has had little effect in reducing superstitious beliefs and uncritical attitudes or in developing consciously reflective abilities to analyze natural phenomena or to test hypotheses.
>
> Emotional and other personality factors are important to success in science careers as well as to daily living. Yet, many conventional practices have negative effects on these factors.

There seems, however, to be common agreement among those who have been thinking about teaching that the tactics and strategy which encourage, support, and emphasize the development of social as well as emotional maturity are more likely to result in success in college, than is the "covering of materials" approach. This too is supported by such meager studies as exist. But it is very clear that research studies on the effect of course structure and content are few; the field is wide open for research.

Long-term policy as a frame of reference

Any long-term plan must be based on general attributes which will pervade the entire program. Two of these, both important and by no means mutually exclusive, have been discussed extensively in the early parts of this book: first, the pattern of behavioral objectives, which centers the instruction upon the learner whose active participation is critical; and second, the general attributes of scientific work, which give meaning to the processes and materials of science. What a teacher accepts as his objectives, and what he interprets as the way of the scientist and the function of science in the lives of students,

[1] R. Will Burnett, *Teaching Science in the Secondary School*, Rinehart, N. Y., 1957, p. 99.

CHAPTER 18

Inventions in science courses:

Building the science course and curriculum, continued

A note at the beginning: We began this chapter eight chapters ago, actually Chapters 10 and 18 must be considered one chapter. For how can a teacher develop his own course or curriculum, or meditate wisely on what he is teaching, unless he has studied what is going on in curriculum work in science?

Having begun with trends in the curriculum (Chapter 10), we now return and develop it further, to the point where the teacher may, if he wishes, develop his own curricular inventions. A warning: building a *new* fresh course takes time: time to read, time to reflect, time to visit other school systems, time to test the course in class, time to consult one's colleagues.

Approach to curriculum revision

The curriculum may be defined as *all* the learning experiences provided under the school's guidance—courses, club work, and extra class activities of all types.

We may ask, then, whether the curriculum in science is so planned and integrated that it teaches what we want it to teach. Too often the honest answer is no. Frequently we present children with a layer-cake program of separate, independent courses. Continuity of learning, increase in comprehension, and development of abilities are not stressed. The trend, noted in Chapter 10, toward the design of a continuous 12-year program in science indicates that the old series of courses is already under close scrutiny. As this effort to create unity and coherence within a science curriculum is extended, where shall we look for guide lines?

Certain guide lines which we have found useful are those which emanate from *research*, from *policy-making statements*, and from experience in the *process of curriculum revision*. The three sections which follow concern them-

selves with these phases: we do this by citing examples of policy and process in curriculum revision.

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In Chapter 21, Appraising the Teacher's Role: Supply and Demand in Science, we indicate that science teaching as a whole has been "successful"; that is, if we view the entire enterprise. In the same chapter, however, we indicate that although valid and reliable data in science education are limited, still, such data as are available support the working hypothesis that Burnett states.[1]

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> Emotional and other personality factors are important to success in science careers as well as to daily living. Yet, many conventional practices have negative effects on these factors.

There seems, however, to be common agreement among those who have been thinking about teaching that the tactics and strategy which encourage, support, and emphasize the development of social as well as emotional maturity are more likely to result in success in college, than is the "covering of materials" approach. This too is supported by such meager studies as exist. But it is very clear that research studies on the effect of course structure and content are few; the field is wide open for research.

Long-term policy as a frame of reference

Any long-term plan must be based on general attributes which will pervade the entire program. Two of these, both important and by no means mutually exclusive, have been discussed extensively in the early parts of this book: first, the pattern of behavioral objectives, which centers the instruction upon the learner whose active participation is critical; and second, the general attributes of scientific work, which give meaning to the processes and materials of science. What a teacher accepts as his objectives, and what he interprets as the way of the scientist and the function of science in the lives of students,

[1] R. Will Burnett, *Teaching Science in the Secondary School*, Rinehart, N. Y., 1957, p. 99.

determine his long-term and short term policy; and policy affects course structure.

One example of long-term planning which takes account of both sets of criteria was issued in 1956 by the Maryland State Department of Education.

To the reader: We consider this an excellent statement of policy. If we had not "discovered" it, we should have had to elaborate one very much like it. Notice the form of these statements, it is close to the pattern of OBJECTIVE: behavior *which we considered in Chapter 6.*

Only the portion dealing with science in the secondary school is included here, the report includes, however, much on both elementary and secondary education.[2]

1. *A good high school science program is organized and carried out to provide for:*
   a. *A growing knowledge of scientific principles. The number and complexity of principles involved in the problems will increase at higher grade levels.*
   EXAMPLES: In the junior high school concepts and principles concerning electrical circuits are simple and few in number. More complex principles are introduced in later courses concerning circuits through electrolytes, vacuum tubes, selenium rectifiers, transistors, and other media
   b. *Facility in making applications to life situations.*
   EXAMPLES Pupils interpret weather forecasts in order to make necessary adjustments in their activities and plans. Pupils experiment to compare the quality and cost of canned with fresh orange juice.
   c. *The development of scientific attitudes and skill in the scientific method[s].*
   EXAMPLES Pupils show curiosity about the earth satellite and new concepts of space. Pupils suspend judgment until convinced by evidence about battery additives and other consumer products
   Pupils seek cause and effect relationships for everyday phenomena such as condensation on basement walls.

2. *A good high school science program seeks to provide for the immediate problems of youth.*
   a. Some problems are personal.
   EXAMPLES: Pupils understand themselves and the changes of adolescence.
   b. Some problems are emotional.
   EXAMPLES: Pupils interpret natural phenomena such as storms, comets, and eclipses, rather than fear them
   c. Some problems are physical.
   EXAMPLES: Pupils know and apply scientific facts about health problems related to the use of alcohol, narcotics, and tobacco, and to heart disease, cancer, tuberculosis, and other diseases.

3. *A good high school science program produces changes in the living of people.*
   EXAMPLES. Pupils demonstrate efficiency in planning and performing tasks such as waterproofing a basement or laying a tile floor. Pupils purchase goods and materials for quality and content. Pupils develop habits of safety which apply to the use of automobiles and home appliances. Pupils practice wise use of fuels, water, and other natural resources.

[2] From "Planning for Effective Learning—Science," Maryland State Department of Education, 1956. Examples abridged, italics added.

4. *A good high school science program provides opportunities to work with everyday materials in the environment.*

EXAMPLES: Pupils collect and maintain living plants and animals in the classroom. Pupils construct science equipment such as motors and animal cages. Pupils study and experiment with automobiles.

5. *A good high school science program implements other curricular areas and is implemented by them.*

EXAMPLES: Science fair project write-ups are examined in the English class for clarity, sentence structure, and paragraph unity. Analysis in science classes of employment data received from the guidance department stresses the opportunity for employment in the field of science. Science teachers teach the exactness of expression.

6. *A good high school science program includes provisions for growth in the use of study and work skills* involved in:

Locating scientific data, handling and using science materials effectively, observing and measuring objectively, recording data accurately and in usable form, generalizing from a body of information, selecting the pertinent elements of a problem, using scientific vocabulary accurately, checking footnotes, using *Readers' Guide to Periodical Literature* and other library resources.

7. *A good high school science program encourages "creative thinking."*

EXAMPLES: A boy with an attic bedroom designs and later builds a planetarium which conforms to the geometrical plan of the room.

8. *A good high school science program encourages the exploration of a wide range of science-related hobbies.* Suitable facilities are provided.

EXAMPLES. An equipped darkroom, an adequate supply of basic equipment and materials, a reasonable supply of specialized and technical equipment, labeled and scientifically classified collections, facilities for club and special activities such as photography, radio, astronomy, tropical fish, horticulture, taxidermy, and mineralogy.

9. *A good high school science program is characterized by experimental activities cooperatively planned by the teacher and the pupils as an outgrowth of their classwork.*

EXAMPLES: Pupils grow seeds in different light conditions. Pupils carry out dietary experiments with white mice. Pupils determine the effects of filters in photography. Pupils develop a conservation-demonstration area.

10. *A good high school science program is facilitated by varied records kept up-to-date by teachers and pupils.*

EXAMPLES: Hobby progress reports, records of materials constructed by pupils, reports of original and voluntary experiments, reports of supplementary research, reports of areas of special interest, indications of the pupil's potentiality as a resource person.

11. *A good high school science program is flexible.*

EXAMPLES: Emphasis on atomic energy is increasing while emphasis on coal is decreasing. Emphasis in rural areas is placed on relative locations of wells and septic tanks, while emphasis in urban areas is placed on obtaining adequate water supply for the city and on filtration systems.

12. *A good high school science program allows pupils to extend themselves along their lines of interest; they explore and discover for themselves in situations less formalized than those which can be provided in the classroom.*

EXAMPLES Time is provided for individual conferences about hobbies and projects. Pupils participate in science clubs under the sponsorship of science teachers.

13 *A good high school science program is made operative under the guidance of teachers who help the pupils to organize their problems and channel their energies toward solutions*

EXAMPLES Pupils depend upon teachers for guidance, not for answers; they get help in locating resource people and information. In the science laboratory primary emphasis is given to the solution of real problems, rather than to the verification of known principles.

14 *A good high school program makes use of a variety of human and environmental resources.*

EXAMPLES. Use is made of people (beekeepers, doctors). Use is made of environmental resources (steel mills, native fish, plants and insects collected by pupils). Use is made of school facilities (greenhouse, radio programs and TV programs, hobby shows).

15 *A good high school science program uses science resources available in the central school library*

Periodicals, science reference books, science fiction, audio-visual aids.

16. *A good high school science program brings pupils to appreciate and assume social and moral responsibility involved in scientific progress.*

EXAMPLES Pupils identify and cooperate in the solution. Pupils are encouraged to discuss the implications of nuclear developments

17. *A good high school science program recognizes an orderliness of the universe.*

EXAMPLES Pupils study the carbon dioxide-oxygen production cycle to see the relationship between animate and inanimate objects. Pupils discover that the structure, weight, and activity of a given element were predictable before the element was discovered Pupils investigate the primary source of protein to give them insight into the dependence of animals on plants.

18. *A good high school science program provides facilities and a wide variety of appropriate materials of instruction in the classroom.*

EXAMPLES: Each teacher should have a self-contained laboratory-classroom designed to provide for a wide variety of science activities. Each science laboratory-classroom should be equipped with a basic supply of texts and references, free and inexpensive materials, experimental equipment and supplies, audio-visual aids, tools, and safety equipment.

This statement of long-term policy and curricular design permits the widest invention in courses and curriculums. It permits the widest emphasis upon intellectual skills and attitudes. It is an excellent framework upon which the science curriculum can be based. The over all objectives are pervasive throughout the entire program, irrespective of the particular materials being considered. The choice of subject area or problem can come from the pupils, and the wise teacher will evoke the searching, appraising, judging, and experimenting which are the major characteristics of science and scholarship in action.

The need for a recognition of bases other than subject matter solely has been examined in many thoughtful publications prepared by eminent groups.

TABLE 18-1 Comparison of emphasis in two curricular plans

Educational Policies Commission		*Harvard*	
Common learnings	1/3	Special education	1/3
Vocational preparation	1/3	English	1/6
Electives	1/6	Foreign language	1/6
Health and physical education	1/6	*Science and* mathematics	1/6
		Social studies	1/6

3. *Education for All American Youth.*[5] The proposals embodied in this report of the Educational Policies Commission were a basic departure from what we know as the college-preparatory curriculum.

First, there was suggested a more flexible school day. Large blocks of time, two or three periods or more in length, were introduced to permit the introduction of a course in "common learnings." This course dealt with basic social processes, communication, distribution of goods and services, family living, etc In it, attention was centered upon the problems and concerns of people in a modern society.

Second, "special education" in the context of this report was taken to mean "vocational education." In the Harvard Report "special education" referred to the special interests of youngsters as designated in fields of study, i e , science, mathematics, art, music, foreign languages, and so forth.

Finally, in the Educational Policies Commission report, separate courses in English, social studies, science, mathematics, and foreign languages are not *required* per se. They are either *elective* or vocational. The Harvard Plan would *require* some of these courses

The differences in curricular emphasis in the two plans are noted in *Table 18-1.*

The process of curriculum revision

As the previous chapters have indicated, the pattern of science courses and their internal design have evolved slowly over the past half century. Only two major changes have occurred in secondary school science: the creation of the unified biology course and the introduction of general science. This slow pace is likely to be accelerated sharply. Too many people are deeply concerned about science in the culture and in the secondary schools to allow the unchallenged continuation of the status quo. The activities of the Physical Science Study Committee are a clear example of other activities to be expected. Teachers will be obliged to take a hard look at what they are doing and why. Innovation will be valued. Clearer concepts of the place of science in the school

[5] Educational Policies Commission, National Education Assn , Washington, D C., 1944.

program, as expressed through classroom operations for diversified audiences of pupils, will be stimulated.

Individualization of instruction far beyond what has been offered within the Procrustean single-track curriculum of the past will be necessary. Greater diversity of courses for different groups of children will be essential. More concern for the slow and for the able will be mandatory. Large changes in science courses and the patterns of such courses, the curriculum, are coming soon.

Such changes will come, if for no other reason, because of the "pressures from below." The rapid development of elementary school science and the extension of general science through grades 7 and 8 are already being felt in many secondary schools. The children already know much of what was formerly considered "secondary school science." This may well be a boon to teachers who do not have enough time to "cover" the increasing content of science. Instead of repeating topics the students have already had, for the same purposes, teachers will need to plan their instruction so that the pupils reveal and expand their previous learning.

In short, the science curriculum will have to change to accommodate these knowledgeable students, and the extent of their knowledge will need to be determined.

Approach to planning

Perhaps our approach to planning needs to be stated explicitly here: *planning with students does not preclude the teacher's private planning of a course or of the sequential blocks of study within the course.* A moment's reflection will bring to mind the consistent and predictable problems which young people face. Year after year they ask much the same questions. This, then, permits the teacher to anticipate the general areas of discussion, the necessary equipment and supplies, reading resources, films, and other instructional materials likely to be useful. Without this kind of anticipation both pupils and teacher will be in a continuous race to locate essential materials.

Planning of this general sort, in broad units, is necessary. Few of us have at hand the rich materials and personal knowledge desirable for effective instruction on any topic that may arise. But general planning is not rigid; flexibility for student involvement is always possible.

For example, the occurrence of some major new discovery can be foreseen as a new center of class attention. Materials can be collected, bulletin board displays encouraged, and the attention of the group channeled to this new topic. Furthermore, investigation of any new topic will necessarily demand a careful examination of what was previously known, and why this is an important addition to, or change in, the previous scientific knowledge.

As we have implied, teaching in this rich and rewarding manner requires the availability of many resources: films, journals, numerous reference books of varied difficulty, resource persons who can help with information and advice, a well-stocked equipment and supply room. But, then, these are necessary for effective teaching even in a completely teacher-dominated approach.

Curriculum revision as a continuous process

Certainly no wise teacher will attempt an *abrupt* change in his course, in his methods, or in the general curriculum. And, of course, curriculum changes are not always to be had for the asking. Many people are involved in any program of curriculum revision, but the teacher plays a major role.

It should be mentioned here that very few curriculums, published by states, counties, or cities, are prescriptive. All the curriculums we have discussed in this section state or, at least, imply that they are meant to be used as suggestions, not fiats. Of course, as we have mentioned before, a teacher cannot depart radically from such a program without consulting his principal or supervisor. But he is rarely completely bound by a published curriculum. Over a period of a few years, gradually new approaches and techniques can be tried. Those found useful are retained, the others are replaced. The curriculum, in the total sense of the term, is continually developing.

If the teacher is a member of a large school system, he is probably aware that curriculum revision is going on all the time. For instance, if the reader will study Table 18-2, "Long Term Plans in Curriculum Development 1956 through 1960" of the Minneapolis Public Schools, he will note that the revision of the science curriculum is part and parcel of a total program of revision of all courses of study. Even as he is reading this section, committees of teachers in the schools of Minneapolis are engaged in this constant round of revision. In this way teachers do revise the curriculum with the aid and counsel of the administrative and supervisory staff.

Implementing curriculum revision

We should be naive in the extreme to assume that the publication of a city or state course of study, however it was developed, guaranteed a change in the classroom operation and methods of all teachers receiving the publication. Why should this be so?

First, communication between science teachers is meager. In some schools those teaching biology hardly know the names of those teaching the physical sciences. Often there is no communication between those housed in the junior high school and those in the senior high school. Teachers in one school system may be completely isolated from those in other systems, unaware of the others' problems or instructional or curricular inventions. In addition, the centering of concern upon subject matter has reduced the spirit of teamwork among science teachers. For what purposes and on what ground should the teachers of "standard courses" in biology, chemistry, and physics meet for common discussions? Narrow subject matter specialization has also tended to isolate science teachers from concern for the total curriculum of the school and from knowledge of the base and substance of curriculums in other schools. Irrespective of the direction taken in curricular changes, knowledge of what others have done, their successes and failures, is essential.

Second, throughout the nation, constructive, sympathetic supervision in science is meager. In certain schools, especially in large schools, science supervisors are provided. Yet in too many schools little effective help to science teachers is provided. Yet new teachers, whether beginners or experienced teachers of other subjects impressed (converted) into teaching science, are in severe need of assistance.[4] Wise teachers may be near at hand, but rarely does there exist a mechanism for bringing the beginner and the "wise old hand" together frequently for constructive discussions, intervisitations, and the like.

Third, there is not enough time. Many science teachers indicate that they simply do not have enough time to teach as well as they might, let alone keep up with new trends. With growing enrollments and a shortage of adequately prepared new science teachers, those in the classroom face larger classes, more papers, more sections, more laboratory equipment. Seemingly there is no end to the continual housekeeping that a conscientious teacher does. (We hope that some of our suggestions in Section V, Tools for the Science Teacher, about laboratory squads, and so forth, may be of some small help in reducing the housekeeping chores.)

Often the needed time for improvement of courses and the over-all curriculum does exist, but is not available for these greatly needed activities, because the teacher feels obliged to take on a second job to meet his financial needs. We do not have an easy answer to this problem, yet we suspect that excellence in teaching will be recognized. With competent science teachers in short supply, communities will find ways and means of retaining or of attracting admired teachers who are effective in teaching children.

Teachers, busy with the day-to-day responsibilities and often carrying a second job, sincerely wonder when time may be available for thoughtful course planning and curriculum development. After-school sessions are, in our experience, relatively inefficient. Summer sessions are perhaps the answer; then school systems would need to allocate greater funds to support their teachers during these "free" months. Possibly the various patterns of governmental and industrial fellowships will come to underwrite this type of summer planning.

Finally, in small schools (over half the young people go to high schools enrolling not more than 400 pupils among all the grades) the curriculum cannot be very flexible. Generally in such schools the basic curriculum is that known as "college preparatory." Yet, as we have seen, nation-wide only about half the children even graduate from high school. Of those who do, around one-third (or one-sixth of the age group) enter college. These facts become even more significant when we consider the wide variations between schools. From some larger suburban schools as many as 75 per cent of the children enter a college, while from some small rural schools only 1 or 2 per cent enroll for further education. Then we have the "college preparatory" program domi-

[4] For evidence of this need of teachers and the lack of help they receive, see: F. G. Watson and Edward Victor, *The Converted Science Teacher*, New England School Development Council, Cambridge 38, Mass., 1957.

TABLE 18-2 Minneapolis public schools: long-term plans in curriculum

1957-1958	Initiation and organization of new program or program to be revised	Development and introduction of experimental materials or program
ELEMENTARY ONLY		Faculty Studies, extend to other schools Functional Spelling, extend to other schools
ELEMENTARY-SECONDARY		Science
JUNIOR HIGH ONLY	Guide to Teaching Electricity	
JUNIOR SENIOR HIGH		
SENIOR HIGH ONLY	Retailing, Basic Business, Typewriting Art Resources—second year on three-year trial basis	Senior High School Day, Study of Office Training, Secretarial Practice
1958-1959		
ELEMENTARY ONLY	Guide to Teaching Reading in the Elementary School (Revised)	Faculty Studies, extend to other schools Functional Spelling, include all remaining schools
ELEMENTARY-SECONDARY		Guide to Teaching Science
JUNIOR HIGH ONLY	Guide to Teaching Graphic Arts	Guide to Teaching Electricity
JUNIOR SENIOR HIGH		
SENIOR HIGH ONLY	Advanced Business Principles, Senior Shorthand, Senior Typewriting, Machine Calculating Art Resources, third year on three-year basis	Retailing, Basic Business, Business Typewriting

* By permission of Dr Rufus Putnam, Superintendent of Minneapolis Schools.

*development 1956 through 1960 **

Year	*Development of more permanent program of materials*	*Introduction of completed program*	*Evaluation of program*
1957-1958			
	Handbook on Reading Center Program Guide to Music Teaching	Faculty Studies, Handbook for Teachers Guide to Music Teaching	
	Guide for Teaching Special Classes Handbook on Evaluating Techniques Curriculum in Health, Physical Education, and Recreation, Kindergarten—12	Speech Correction in practice Social Studies Curriculum	
	Reading, Guide to Reading, Listening, and Viewing Guide to Teaching Metalwork	Guide to Teaching Woodwork	
	Scope and Sequence in Business Education Shorthand I Shorthand II Bookkeeping	Guide to Teaching Mechanical Drawing	
1958-1959			
		Handbook on Reading Center Program	Functional Spelling
		Guide for Teaching Special Classes Handbook on Evaluating Techniques Curriculum in Health, Physical Education and Recreation, Kindergarten—12	Communication, Guide to the Teaching of Speaking and Writing
		Reading, Guide to Reading, Listening and Viewing Guide to Teaching Metalwork	Guide to Teaching Woodwork
	Office Training, Secretarial Practice	Scope and Sequence, Shorthand I, Shorthand II, Bookkeeping	Guide to Teaching Mechanical Drawing

TABLE 18-2 (cont.)

1959-1960	*Initiation and organization of new program or program to be revised*	*Development and introduction of experimental materials or program*
ELEMENTARY ONLY		
ELEMENTARY SECONDARY		
JUNIOR HIGH ONLY	Guide to Teaching Graphic Arts	
JUNIOR SENIOR HIGH		
SENIOR HIGH ONLY		Senior Shorthand, Senior Typewriting, Machine Calculating, Advanced Business Principles

nating in the smaller schools, which have the *fewest* collegiate aspirants and the largest numbers of terminal students.

While there are surely many other factors acting to retard curricular changes, one other must be mentioned: many teachers underestimate themselves. All teachers can produce changes in the curriculum; they do so every time they face a class. All teachers can offer their suggestions, even in the face of apparent rejection. They can do no less.

As we mentioned much earlier, a beginning teacher should adapt to his school situation for the first year or so. After all, the practices in the school are the result of long experience, and his is relatively short. But as he progresses toward becoming a skillful teacher, surely his sense of responsibility will demand that he do whatever he can to improve not only his own teaching, but also *the framework within which he teaches*.

The cases of curriculum development cited earlier, along with many others, originated in one way or another in the initiative of teachers (whether these be teachers who have taken on the additional responsibility of becoming experts in curriculum or not).

An extended excursion into developing one's own curricular invention

When a teacher tries to improve his course of study, or is part of a committee to develop a "new" curriculum, he is actually on the search for "new directions" in science teaching. Perhaps these directions in curricular revisions

Development of more permanent program of materials	*Introduction of completed program*	*Evaluation of program*
Guide to Teaching Reading in the Elementary School (Revised)		Handbook to Parents on Elementary School Curriculum
Guide to Teaching Science		Social Studies Curriculum
Guide to Teaching Electricity		
		Guide to Teaching Metalwork
Retailing, Basic Business, Business Typewriting	Office Training, Secretarial Practice	Scope and Sequence, Shorthand I, Shorthand II, Bookkeeping Art Resources, evaluation of three year trial project

would be useful. How does he proceed? Logically he would proceed by examining the literature. A selected portion of it has been offered throughout this section; more references will be suggested here. Possibly these attempts will indicate the directions, some "new," some "old," which might prove of value to him.

In many school systems and schools, the beginning teacher finds a curriculum. But as soon as he begins teaching, he begins to think of ways to modify his courses and his curriculum. Soon he is asked to become part of a committee to revise the curriculum. If he is the only science teacher in a school, or one of two or even three, the position he takes with regard to the curriculum becomes especially important.

Whether the teacher is a member of a large school system or small, his curriculum will generally consist of one of the following patterns, or some combination of them, or of the type of variations discussed in items 18-1, 18-2, and 18-3 (pp. 381-84).

Pattern A: standard sequence

If the pattern of classes indicated in Chapter 3, Science Classes, conforms to your ideas, if the kinds of courses we have detailed in the preceding chapters on curricular inventions are similar to your own, present or projected, then it is probable that you will devise your curriculum to include the *four major types of courses.* In addition, you will probably make *provision for the science shy and the science prone* as indicated in Chapters 8 and 9.

If you have been collecting courses of study, you have a remarkable collection which should serve you well. You not only have the major courses, but

you have the various types of courses given in any community or even a nation [7] with special needs and interests. Also, many school systems have curriculum libraries with good collections of courses.

Pattern B: substitute courses

You may have tried or examined the so-called college preparatory curriculum, and have concluded that the objectives you hold for the education of young people are not adequately met by the courses in that curriculum.

Perhaps you will want to evaluate or try one or more *substitute courses:*

1. A course in "physical science" for those students who do not take, or cannot take, physics or chemistry (see p. 343).

2. A course in "advanced science" for students who want to be scientists. This course is mainly built around project work (see p. 182).

3. A course in "earth science" for students who seem not to do well in mathematics (see p. 339).

Pattern C: a core curriculum

Perhaps substitute courses do not fit your purposes. Possibly your objectives and your training lead you toward development of a *core curriculum* around the special needs and interests of your students and their community.

We mentioned briefly the core approach on page 363. The available evidence indicates that only teachers of wide knowledge and considerable teaching skill will be successful in a core program. Often a social studies or English teacher, who lacks personal study in science and the continuing assistance of a well-informed science teacher, will ignore or fail to see and develop the implications of science in the core area. Burnett stresses this point in his able discussion of the difficulties of the core approach in science.[8]

Should you care to explore further into the core approach and general techniques in the development of the high school curriculum, the following books will be helpful.

Alberty, Harold, *Reorganizing the High School Curriculum*, N. Y.: Macmillan, 1947.
Leonard, Paul, *Developing the Secondary School Curriculum*, N. Y.: Rinehart, 1953
Stratemeyer, F. B., H. L. Forkner, and M. G. McKim, *Developing a Curriculum for Modern Living*, N. Y.: Bureau of Publications, Columbia University, 1947.

After these introductions to the core, you may want to study specific analyses of "cores" in practice.

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[7] Fifteenth International Conference on Public Education, *Teaching of Natural Science in Secondary Schools*, Bureau of Publications, Teachers College, Columbia U., N. Y., 1952. (Convened by UNESCO and the International Bureau of Education at Geneva.)

[8] R. Will Burnett, *op. cit.*, pp. 293-315. See also *The Core Program, Abstracts of Unpublished Research, 1946-1955*, U. S. Office of Education Circular 485, Washington, D. C., 1956.

For instance, Lorge* compared experimental core-type and control groups (taking established courses) by objective measurement in vocabulary, science achievement, algebra, and contemporary affairs. He concluded that students in the core-type program were equal to, or superior to, the control group on every objective measure.

Other sources which detail evaluations of practical experience in core work are:

Capehart, B. E., A. Hodges, and N. Berdan, "An Objective Evaluation of a Core Program," *School Review*, 60:81-89, Feb. 1952.

Core Curriculum in Philadelphia: An Analysis of Principles and Practices, Curriculum Office, Philadelphia Public Schools, May 1949.

Oberholtzer, E. E., *An Integrated Curriculum in Practice*, Bureau of Publications, Teachers College, Columbia University, N. Y., 1937.

Wright, G., *Core Curriculum*, Office of Education Bulletin No. 5, Federal Security Agency, 1952.

Pattern D: four years of science

Perhaps you will not be satisfied with a core program or substitute courses. Perhaps you have examined what has happened to the curriculum in English, and wondered whether it is possible to similarly "meld" the work in *four years of science*.

Perhaps you feel this to be a useful attempt because you believe that mere substitution of one course for another—i.e., physical science for chemistry and physics, biology for general science, or earth science for general science—or whatever seems to be the intent of "trial and error" curriculum making is not desirable. We, you may remember from your reading on p. 324, burned our curricular fingers severely by attempting to substitute biology, then chemistry, for general science; however, we didn't get to do so for physics.

The major reason for our failure, and we acknowledge it, was our peculiar notion that "good and interesting" teaching can get students to learn almost anything. We tend to suspect that most boys and girls of an I.Q. around 100-110 *cannot* in the ninth grade master physics and chemistry *as usually given* in the eleventh and twelfth grades, nor biology *as usually given* in the tenth grade. Our experience was that youngsters of equivalent I.Q. made considerably lower grades in the same tests in the ninth grade. We gave our reasons (on p. 325) for suspecting that if these courses are offered in the ninth grade, they need to be fitted to ninth-grade youngsters.

In any event, if only because earlier we promised to detail a course in four years of science, we present our efforts here. Time will tell whether the "course approach" (separate courses), the "fused-curriculum" (Science, Four Years) as detailed immediately following, the "core approach" (see Pattern C in this

* Irving Lorge, "Curriculum Evaluation—Bronx High School of Science," *High Points*, 24:27-37, May 1942.

you have the various types of courses given in any community or even a nation [7] with special needs and interests. Also, many school systems have curriculum libraries with good collections of courses.

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[8] R. Will Burnett, *op. cit.*, pp. 293-315. See also *The Core Program, Abstracts of Unpublished Research, 1946-1955*, U. S. Office of Education Circular 485, Washington, D. C., 1956.

tween the desires of the individual and the desires of the society in which he lives, so problems of living generally involve the interaction of an organism (a biological entity) with its physical and chemical environment. This is merely to emphasize that problems of our world are solved by individuals who can correlate or fuse different areas of experience. This basic purpose is best met by similar learning experiences devised in school.

The sequence shown in Table 18-3 must be modified for each individual school. One of the advantages of this organization is that subject matter is used only as it answers a desirable or necessary problem. It should be clear that a complete syllabus cannot be presented; the lettered topics in the outline are merely suggestive and should serve as a frame of reference.

We do not contend that this pattern of courses has any greater merit than another which the reader may invent. But we do say that:

1. The conventional structure of the curriculum in terms of general science, biology, chemistry, and physics need not be fixed.

2. The trend toward election of four years of science by all pupils will be accelerated when a continuous program of courses in science, given over four years, has been adopted.

One advantage of a continuous program of four years in science is especially interesting. It might abolish the tension between schools and colleges about "preparatory courses" that do not seem to "prepare." Surely a student taking four years in a continuous program would know much about the various areas of science. He might be strongly "prepared" for collegiate work, especially through a knowledge of how to define and attack problems, how to use the library and equipmental resources, how to think and operate in science.

Teachers in such a program would be "science teachers," not biology teachers or physics teachers or chemistry teachers. While this change in title to the equivalent of "English teacher" or "mathematics teacher" might seem novel, most teachers of science in the United States, of necessity, already teach more than one science; in the small schools (predominant in the U. S.), many teachers of science teach all the different sciences.

18-1. These four patterns by no means sum up the possibilities. For instance, you may want to read *New Directions in Science Teaching*.[10] This volume reported on a cooperative project between seventeen serondary schools and the Bureau of Educational Research in Science, Teachers College, Columbia University, between 1940 and 1942. One teacher from each of the seventeen schools (13 public and 4 independent) worked together for three summers with a large staff under the general supervision of Professor S. R. Powers. Many useful new rourses were designed. Among the interdepartmental courses were:

Integration of All Subjects in Ninth Grade (Bronx High School of Science, New York City)

[10] A. D. Laton and S. R. Powers, *New Directions in Science Teaching*, McGraw-Hill, N. Y., 1949.

section), or still some other approach will become the curricular trend in science in the future.

In the years 1945 to 1953 several trial runs were made at the Forest Hills High School of a course titled "Science, Four Years." The attempt was to develop a four-year course cutting across subject areas. The youngsters who took this course (74 in two groups) certainly did as well in standard examinations and in the College Entrance Board Examinations as did a control group. Since the number of students was small, we are not going to elaborate statistics, but simply give our observations, i.e., that these youngsters had opportunity to see science in relation to their problems, their own needs and interests; that these youngsters had freedom *and time* to discuss ethical and emotional problems; that these youngsters saw science in relation to its social context. Furthermore, the teacher had *time* to teach because he taught the material when it was relevant, he did not need to refer back hopefully to another course where the material was taught and possibly learned.

For instance, when respiration was studied, the structure and function of the respiratory organs were examined, alveolar structures were studied under the microscope, dissections were made, oxygen and nitrogen were prepared, and their properties (in relation to respiration) were studied; and the principles affecting the behavior of gases were considered. In this very brief account of a minute division of science, it is clear that subject matter usually considered under general science, biology, chemistry, and physics is combined into one experience concerned with a life problem.

The four years of science were titled: *Science and the Individual, Science and the Family, Science and the Community,* and *Science and the World.* These titles were not merely names. Emphasis was not placed on subject matter, but it was learned only as it served the personal, socio-personal, socio-civic, and socio-economic needs of the individual. The need of the individual to be a healthy functioning citizen involves biology and chemistry, as well as physics and other fields. The need of the individual to be adequately housed is related to: the biology, chemistry, and physics of sewage disposal; the biology of the effect of sunlight on growth and disease; the chemistry of construction materials; the physics of forces and movements; refrigeration and ventilation—to mention but a few aspects. In a science curriculum based upon a traditional pattern, the teachers of chemistry, biology, and physics delay or avoid a comprehensive discussion of any problem until another cubicle of science is mastered. In fact, many of them console themselves by answering a student's questions with the evasive statement, "We can't take this up here; wait till you get to physics." Possibly the boy or girl never reaches physics. Almost certainly the pupils fail to see the totality of scientific factors which influence their lives daily.

If it is a requirement of our age that boys and girls must understand their environment, then teachers of science must fulfill their function by furnishing the continuous experiences necessary for the understanding of related problems. And in much the same way that a developmental task is an interaction be-

tween the desires of the individual and the desires of the society in which he lives, so problems of living generally involve the interaction of an organism (a biological entity) with its physical and chemical environment. This is merely to emphasize that problems of our world are solved by individuals who can correlate or fuse different areas of experience. This basic purpose is best met by similar learning experiences devised in school.

The sequence shown in Table 18-3 must be modified for each individual school. One of the advantages of this organization is that subject matter is used only as it answers a desirable or necessary problem. It should be clear that a complete syllabus cannot be presented; the lettered topics in the outline are merely suggestive and should serve as a frame of reference.

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TABLE 18-3 Science—four years *

First year Science and the individual

I. Problems in adequate nutrition
   A. Kinds of food
   B. Nutrients
   C. Chemistry and physics of digestion and absorption
   D. Chemistry of oxidation
   E. Diets in relation to health
   F. The consumer

II. The function and structure of the body
   A. Biology, chemistry, and physics of respiration
   B. Biology and chemistry of blood, physics and biology of blood pressure
   C. Vision and hearing
   D. Introductory physics of light and sound
   E. Chemical tests of urine and sweat
   F. Excretion
   G. First aid

III. Prevention of disease
   A. Water borne diseases
   B. Air borne diseases
   C. Human carriers
   D. Infection and contagion
   E. Applied chemistry of antiseptics and chlorination
   F. Immunity
   G. Public health measures
   H. Sewage disposal

IV. A person's behavior
   A. Structure and function of the nervous system in relation to learning and to habit formation

V. Leisure activities
   A. Photography
   B. Nature-study
   C. Pets
   D. Tropical fish
   E. Growing plants
   F. Radio
   G. Engineering activities
   H. Airplane models and aviation

Third year Science in the community

I. Eugenic factors
   A. Improvement of the individual as a community problem
   B. Feeblemindedness
   C. Birth rate and death rate
   D. War as a destroyer of germ plasm and productive citizens

II. Personal services
   A. Recreation
   B. Medical services
   C. Education

III. Improvement of food
   A. Chemistry and biology of photosynthesis
   B. Heredity and biologic production

IV. Improvement of soils
   A. Chemistry of soils, hydroponics
   B. Practical gardening
   C. Fertilizers
   D. Physics of erosion
   E. Biological organisms
   F. Agricultural practices

V. Conservation of resources
   A. Coal, metals, minerals, and mining
   B. Forest and lumbering practices

VI. Housing
   A. Chemistry of materials
   B. Physics of structure
   C. Heating, ventilating, humidifying, refrigeration
   D. Biologic factors

VII. Energy
   A. Chemical energy for muscles, including a fuller analysis than usual of chemical changes in blood and muscles
   B. Machines
   C. Fuels, water power, electricity
   D. Future of atomic power

VIII. Communication
   A. Telephone, radio, radar, television
   B. Automobile, locomotive, airplane
   C. Fuller treatment of light, sound, and wave physics
   D. Electronics
   E. Chemistry and physics of the combustion engine
   F. Aviation physics

* P. F. Brandwein, "Four Years of Science," *Science Education*, *29*, 29, Feb. 1915

Second year: Science and the family

I. Reproduction
   A. Common animal reproduction
   B. Individual or group conferences on human reproduction where classes are mixed, or class discussion in segregated classes
   C. Prenatal and postnatal care

II. Heredity
   A. Principles of heredity
   B. Environment and heredity
   C. Application to human beings
   D. Marriage
   E. The early environment of the infant

III. Safety in the home
   A. Prevention of accidents
   B. The medicine cabinet
   C. Review of first aid

IV. The home chemist
   A. Chemistry of cooking and cleaning
   B. Chemistry and physics of clothing

V. The home electrician
   A. Understanding electrical appliances at home
   B. Practical experience

VI. The home biologist
   A. Maintenance of food to avoid spoiling
   B. Elements of nursing the sick person
   C. Growing plants
   D. Care of pets
   E. Care of young children

Fourth year: Science and the world

I. Science and technology
   A. Effect on world economy
   B. Employment, leisure, communication
   C. Interrelationship among people

II. Racial understanding
   A. Evolution of man and human races
   B. Brief psychology of human relations

III. The life span
   A. Birth rate and death rate
   B. Factors affecting productive life and health

Integration of Science and Social Studies (Edwin Denby High School, Detroit)

Integration of American History and Chemistry (Olney High School, Philadelphia)

Integration of Science and English (Arsenal Technical School, Indianapolis)

Core Course on Human Living (Lincoln School, New York City)

Integration of Chemistry and Economics (Cranbrook School, Bloomfield Hills, Mich.)

Correlation of Biology and Home Nursing (George Rogers Clark High School, Hammond, Ind.)

English–Science Course (New Trier Twp. High School, Winnetka, Ill.)

Many existing courses were modified. In biology the emphasis turned upon human development and growth. In the physical sciences the emphasis was

riculum. What differences do you find in intent? In content? In phraseology?

18-4. Explore the curriculum revision under way in your school, or a school nearby. Is it being done under a long-term plan like that of Minneapolis? How was the revision started? What enthusiasm for it exists among the teachers? When and how often do the committees meet? What sources of information and ideas are used by the science committee?

18-5. Have you seen your state's recommended science curriculum for the secondary school? For the elementary school? On what basis was either constructed? How old is it? What further modifications are being developed now?

18-6. If you are now teaching, which of the inhibitors to curriculum development discussed in the subsection entitled Implementing Curriculum Revision operate in your school? What other deterrents can you identify? How would you overcome those that seem most serious?

18-7. In what ways is the science department in your school, or a nearby school, feeling the pressures discussed on page 371? What lines of action are being considered? Do you consider these actions adequate for the present? For ten years from now?

18-8. What pattern of contact exists in your community between the science teachers in the junior high school and those in the senior high? How much cooperative planning goes on to ensure continuity of instruction and a minimum of duplication?

18-9. Have you the texts for "new courses" in science, e.g., physical science? Have you examined the various texts concerned with the courses you teach? In a sense, a text is a suggested course of study.

18-10. What possibilities do you see in courses titled:

(a) Technology in Today's World
(b) Biology and Statistics
(c) Chemistry of the Body
(d) The Scientist's Way
(e) Psychology for Seniors

18-11. The curriculum shown in Table 18-4 is an example of one recommended for the full range of students. (Notice that the excerpt we present concerns courses only; activities and projects such as those discussed in Chapters 8 and 9 are also part of this curriculum.) The pattern shown differs for the science prone in that earth science is offered for only these students in the ninth grade and advanced or college-level courses in the twelfth grade. In other parts of the country a few schools are offering biology in the ninth grade for the accelerated program.

We have occasion to wonder: Is the clue to developing the science prone the *covering* of more subject matter or the *uncovering* of it through making available the time and the opportunity to deal with "original" problems in

Section Four | DETERMINING THE SUCCESS OF SCIENCE TEACHING

As Socrates said, "The unexamined life is not worth living." Teaching too requires constant appraisal; even as the teacher examines himself and his goals; even as he examines himself as a human, aside from his goals as a teacher. Every thoughtful teacher wishes to know as clearly as possible what effects his course has upon the students. He wants this information for four main purposes.

1. *for changing and improving his teaching*
2. *for analyzing the strengths and weaknesses of individual students*
3. *for predicting how they may perform in the future*
4. *for grading his students*

These are four separate operations which the teacher desires from his evaluation. If the first three become slighted through emphasis upon the fourth, useful information that would help the teacher appraise his teaching will be lost.

Somehow we must assess the learning, or changed behavior, resulting from our teaching. Such evaluation is inevitably two-way, for the accomplishments of the students mirror our effectiveness. Often we are unhappy over what we see and find, but we must consider the results realistically in terms of the potential of the students as well as our own efforts. What we need is thoughtful appraisal based upon extensive information.

As we consider evaluation we are concerned with more than just testing. Evaluation is based upon the day-to-day observations in the classroom, upon the students' intellectual and emotional growth, upon our expectations for their futures. Observational means as well as tests of various types provide the information needed. A general approach to evaluation, with examples, requires a full chapter, Chapter 19. Chapter 20 considers special teacher-made evaluation devices, and some suggestions by which the teacher may improve his tests and his interpretations of their results. The third and final chapter of the section considers the science teacher in a larger context—as the key to successful science teaching, as a national resource.

science (Chapter 9)? What evidence is there that one approach is more effective than the other?

TABLE 18-4 A four-track science curriculum *

	Accelerated	*Regular academic*	*General*	*Vocational*
GRADE 7 8	general science	general science	general science	general science
GRADE 9	earth science	general science	general science	general science or related science
GRADE 10 12 †	biology chemistry physics advanced or college level science	biology earth science chemistry physics	biological science physical science	related and applied sciences in vocational and prevocational programs

* From *Biology, Topics and Understandings for a Course of Study in the Science of Living Things*, The University of the State of New York, Albany, 1958.
† These are the courses offered in the tenth, eleventh, and twelfth grades, they are electives. The courses shown for grades seven through nine are required.

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CHAPTER 19

Appraising the student:

A general approach to evaluation

A note at the beginning Initially we must emphasize one point: Students are "test conscious." If your principal means of evaluation is tests, as it probably is, the students will be guided in their study and image of the course by the kinds of tests you give. If your tests emphasize recall, the students will memorize and "cram." If your tests emphasize reasoning and understanding through extensive evidence and application, they will strive to reason and understand, as well as to recall what seems essential. If your tests emphasize the College Boards or the Regents Examinations, the students will aim at these limited goals Tests thus are powerful teaching tools; they help set the tone of your instruction and of the students' learning. The tests you give are the students' clue to your real objectives.

Purposes of evaluation

Evaluation can, as we noted in the introduction to this section, be used for at least four different purposes; and we must be sure that our techniques serve the particular purpose or purposes we have in mind. But the phrase "purposes of evaluation" can be read another way: what it is that we want to evaluate, other than the effect of our teaching upon pupil attainment of our many types of objectives.

What to evaluate for

We can evaluate students for:

1. Achievement (the degree to which each student has mastered certain information, manual skills, and intellectual procedures).

2. Diagnostic purposes (to clarify to ourselves and the students their specific strengths and weaknesses).

TABLE 19-1 Sources of information

Intent	*Scores of individual pupil*	*Scores of class*	*Techniques*
1 *Achievement (specific knowledge, skills, concepts, attitudes)*	Initial status, growth, prediction of future growth	Teacher effectiveness when compared to other classes, other years, other schools, other material of instruction, national norms	Observation and tests, both local and standardized, with norms
2 *Diagnosis (general habitual response patterns)*	Diagnosis of individual pupil, treatment in class, changed behavior, prediction of future behavior	Teacher's methods, choice of material for instruction	Observations, special tests, student conferences, and anecdotal records
3. *Prediction*	Future behavior		Observation, achievement and special examinations, conferences, and anecdotal records

3. Predictive purposes (to provide a basis upon which future behavior of the student may be forecast).

4. Effectiveness of a particular teaching procedure.

Generally it is wise to perform these varied evaluations separately. Each is likely to involve special tools or circumstances for the specific purpose. If these distinctions are not made, we may obtain a result, but we will not know what it means. A tabular analysis of these different functions as they relate to individual pupils, to the group, to the teacher's behavior, and to the techniques of evaluation (Table 19-1) may clarify these distinctions. Some overlap between purposes and operations for evaluation is unavoidable, but at least we have a framework within which to consider evaluation.

What to evaluate

Teachers may lose their sense of perspective when they approach evaluation, whether observation of pupils or the formation of a test. Without clearly phrased objectives, they may prepare a test or a situation mostly involving recall (memorization) with perhaps a bit of application to "academic" problems. This is unfortunate, for pupils often believe (with justification) that whatever the test requires is what the teacher really wants of them.

A way out of this confusion is readily available: *write your objectives in behavioral form* and specify appropriate subject material. Some of the recognized opportunities to evoke these behaviors will not be used in class; these are ideal for later evaluation.

Most professional test makers approach their task with this operational view. If you serve on one of their test-forming committees, you will be asked "What do you want the students to be able to do?" If you respond with general terms like "understand . . ." or "apply . . ," they will ask for specific examples defining these terms. As we have emphasized (Chapter 5), general objectives and observable behaviors should be planned together. You may wish to start with the objectives and search for behaviors or start with the behaviors and search for the generalized objectives·

> Both methods of determining objectives and evaluation procedures are in use. *Neither procedure* stands alone, each influences the other through feedback. Initial objectives cannot be defined without consideration of how, when, and where they may appear in the life [behavior] of the student. Similarly, initial formulations of problems to which certain reactions are desired cannot be done *in vacuo*, but must in turn be related to certain socially desirable behaviors Since the evaluation and the objectives of a course must be consistent, they will, over a period of time, interact to the clarification of both in much the same way that experiments and hypotheses interact in a scientific study Some instructors will proceed most rapidly starting with one aspect of the problem; some will find the other more congenial; all will eventually consider the same problems.[1]

Often in the selection or construction of evaluation techniques much concern is given to the *form:* essay, performance, observation, report, true-false, completion, multiple-choice, matching, and so on. But these are only devices to be used as appropriate (they are discussed in this chapter under the heading, "Techniques of Evaluation"). Thoughtful concern must *first* be given to the knowledge, skills, attitudes, and abilities to be appraised.

While there probably will never be a complete list of attributes to be appraised, and while each teacher will want to emphasize different ones, some common and Important elements can be isolated. An interesting and useful analysis of objectives of teaching in the physical sciences was published by Nedelsky:[2]

> 1. Knowledge. The main ability to be tested for in the exercises under this heading, or at least the ability that can most reliably be tested, is memory.
>   1.1 Subject matter knowledge (straight memory questions)
>   1.11 Knowledge of laws and principles (verbal and mathematical).
>   1.12 Knowledge of theories.
>   1.13 Knowledge of facts (e g, density of Iron).
>   1.14 Knowledge of technical terms, symbols, units, dimensions, etc.
>   1.2 Analytical knowledge. Knowledge of relations or patterns studied in the course, it is of a more functional nature than subject matter knowledge (1.1). These relations or patterns are to be tested for in *nearly the same* context in which they appeared in the course
>   1.21 Knowledge of the relation between empirical generalizations (laws of nature) and specific phenomena.

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[1] F. G. Watson, *General Education in Science*, ed. by I. B Cohen and F. G. Watson, Harvard U Press, Cambridge, 1952, p 208

[2] Leo Nedelsky, "Formation of Objectives of Teaching in the Physical Sciences," *American Journal of Physics, 17*, 345, 1919

1.22 Knowledge of the bases of theories; of relation between theories and facts.

1.23 Knowledge of experimental procedures; factors affecting the validity of the experiment, etc.

1.24 Knowledge of the appropriate sources of information.

1.3 Knowledge of methodology. Knowledge of the structures of the separate physical sciences, the relation of these sciences to one another, and their relation to other fields. (Only those specifically taught in the course.)

1.31 Knowledge of the nature and structure of the physical sciences.

1.32 Knowledge of the historical development of the science.

1.33 Knowledge of the realm of the physical science and its branches.

2 Ability to use the methods of science. In this section it is desired to know what the student can do when more or less on his own. It is therefore necessary that the situations used contain elements that are new to the student. [Yet] these should be of the same kind as those studied in the course.

2.1 Ability to use methods of science in abstract situations—well defined and clear cut with a minimum of [recalled] content knowledge required.

2.11 Ability to apply stated principles.

2.12 Ability to carry out symbolically indicated operations.

2.13 Ability to use syllogisms

2.2 Ability to use methods of science in "academic" situations. New to the student, but of a complexity similar to those used in the course. A single principle, law, or theory suffices for the analysis.

2.21 Ability to relate empirical generalizations (laws of nature) and specific phenomena. The particular relation should be new.

2.22 Ability to relate theories and facts.

2.23 Ability to analyze and criticize an experiment.

2.3 Ability to use methods of science in "whole" situations. More complex than those in 2.2, not taught, requiring more than one principle for their analysis.

2.31 Ability to use methods of physics.

2.32 Ability to use methods of physical sciences.

2.33 Science and Society.

3 Ability to read scientific literature.

3.1 Ability to read a book or long article.

3.2 Ability to read a passage.

3.3 Ability to interpret tables, graphs, drawings, etc.

3.31 Ability to interpret a table of values.

3.32 Ability to interpret graphical data.

4. Proper attitudes and habits. This may be approached as effectively through the wrong answers of the student as through his correct answers. The list below is only a sample.

4.1 Attitude of overcautiousness vs. that of jumping to conclusions or going beyond data.

4.2 Attitude of underestimating the power and value of science vs. that of overestimating these or depending on the methods of empirical science in the fields of philosophy, religion, etc.

4.3 Attitude of underestimating the value of experiment or observation as tools of science vs. that of underestimating the importance of reason or of the man-made nature of science.

4.4 Possession of strong prejudices or preconceptions.

4.5 The habit of learning things well, or not at all, vs. that of learning something of everything.

Little change would seem necessary for this analysis to apply equally well to the life sciences too. (Notice particularly Nedelsky's introduction of the distinction between "academic" contexts, point 2.2; those carefully reduced to only pertinent information, and those in "whole" situations, 2.3, in which the student must select what is pertinent.) This effort to produce a taxonomy of *testable operations (behaviors)* was illustrated by an extensive manual of *pertinent test items*.[3] A similar taxonomy has been formed by Benjamin Bloom,[4] and used by Paul L. Dressel and Clarence H. Nelson [5] for organizing some 2,000 test items.

No claims were made by Nedelsky, by Bloom, or by Dressel and Nelson that their taxonomies are complete. Yet they are most useful, for they direct attention to significant operations we may wish to test.

Summary

Before doing any evaluating a teacher must know:

1. What the evaluation is for, what purpose it is to serve for him and his students.
2. What his teaching objectives are, and what behavior on his students' part will tell him whether they have been achieved.

Then, and only then, can he turn to the problem of what evaluation techniques to use.

Techniques of evaluation

At the very beginning of a discussion of techniques of evaluation we must face a difficult problem which bothers all teachers and others involved in evaluation: How good is any evaluation technique? This problem is usually analyzed in terms of two factors: *validity* and *reliability*. *Validity* refers to the degree with which a test measures or describes what it is supposed to measure. It is the answer to the question: Are we testing what we believe we are testing? If only we always had such a clear criterion as the time it took each student to swim 50 yards! There the student performs directly the operation we wish to measure; such a test is said to have "face validity." Generally in school work we wish students to develop hidden "mental" abilities, subtle, invisible understandings, and judging skills. Then we cannot be sure; we can only hope or assume that the particular operations required of them do involve the abilities we are attempting to appraise. In the effort to obtain greater validity, you

[3] Available from Dr. Leo Nedelsky, *Committee of Examiners, University of Chicago*, Chicago, Ill., for $1.00 per copy.

[4] *Taxonomy of Educational Objectives*, Longmans, Green, N. Y., 1956.

[5] *Questions and Problems in Science, Test Item Folio I*, Educational Testing Service, Princeton, N. J., 1956. The folio is quite excensive ($25) and deals with test items for college courses.

will search earnestly for opportunities in the classroom, in the laboratory, and after school when you can observe directly at least some of the characteristics you wish to evaluate.

Reliability is the term used to describe the degree of consistency or repeatability of a student's score on a particular test as a whole. That is, how accurately does it measure whatever it does measure? If the student were to repeat the test without any benefit from the first experience, would the second score be near the first? We would not expect it to be identical because children change from day to day and even hour to hour. Unless we are confident that the recorded score is close to what we would have obtained on a second or even a third trial, we cannot be secure about the significance of the score.*

Objective tests, because they include many samplings of the student's knowledge and skill, are more reliable than are essay tests, although the claim can be made that they are often less valid. Direct observation of pupil behavior is just as important as tests in providing opportunities for valid and reliable evaluation. Self-evaluation and student participation in setting and appraising their behavior standards are also quite useful.

Observation

We have suggested that both classroom and laboratory can provide many opportunities for evaluating, with high validity and reliability, the behavior of students.

Some teachers may immediately begin to worry lest their observations be less reliable or more "subjective" than paper-and-pencil tests. This is of course possible, but it is not necessary. First, observations need not be biased. If all the pupils have equal and comparable opportunities to respond in the desired manner, there is a basis for fair evaluation. Also, the teacher aware of potential bias will do all he can to reduce it. The clearer the statement of behavior sought, the clearer will be the evaluation. Anecdotal records should report the observed behavior and then separate interpretive comments.

Day to day observations of children, "getting to know them," can provide much information about their developing skills, attitudes, and behavior patterns. In addition to observation of the students in naturally arising situations, the teacher can contrive situations to observe.

In any case, some form of written record of reactions to various situations is desirable. Such notes could readily go into a student's cumulative record file. A file card or a record sheet per pupil is probably adequate. Entries reporting what the student did and the conditions under which he reacted this way will be more valuable than comments that his behavior was "good" or "bad." At a later time, perhaps near graduation or when he is applying

* A Joint Committee of the American Psychological Association, American Educational Research Association, and National Committee on Measurement Used in Education has provided a more complex analysis of validity and reliability; see "Technical Recommendations for Psychological Tests and Diagnostic Techniques," *Psychological Bulletin*, *51*, 2, part 2, pp. 13-16, 28.

for a job, such records will be especially useful as they describe the strengths and weaknesses of the student. They will provide a basis for predicting how he will react under similar conditions in the future. Whether or not you use such records in preparing grades depends upon the grading policy of your school. But surely this information is useful to the students and their parents, to the guidance department, and above all, to you, the teacher.

In addition to supplying information about the students which may be difficult to obtain from a test, direct observation can be used to appraise the validity of a test: if there is a high correlation between the scores on a test designed to evaluate a characteristic and the direct observation of that characteristic, we are one step closer to knowing that our test is valid.

Let us discuss briefly the various types of observation and the information we can obtain by their means.

Observation of classroom participation. Students attend classes daily. Daily they participate in the class work or they should (see Chapter 7). When they do, the teacher can, and does, observe the *quality* of the students' participation. This, however, does not mean that the student *recites* in answer to test items stated orally (the teacher's questions) and is rated on his responses. *The net result of making the classroom a constant testing period often destroys the tendency of the students to participate; there is the constant presence of a threat.*

Several teachers we have observed use another method, to us a more useful one for evaluation and for stimulating discussion. Each day they note:

1. Who participated in the class discussion.
2. The general quality of the contribution.

At the end of the week each is assigned a letter grade (A, B, C, D) for the week's discussion. At the end of the first month they have a pretty fair idea of who the leaders in discussion are, and the quality of their leadership. More than that, they know who has not contributed, these students then may be called upon in class (stimulated to contribute), interviewed to detect problems, and given advice and guidance.

Observation of group work. Similarly, group work can be noted and rated. Each student in a group, whether it be a committee or project group, might then be given individually the group rating (i.e., if A is the rating, then each student receives an A) or each student can be rated on his performance within the group

For further comments on the report, see Section V, Tools for the Science Teacher: The Report.

Observation of homework. Students *do* homework, whether this be formal or not. Sometimes, especially if problems have been assigned, the work is rated (0 to 10 or A to F). Then the homework grade is part of the final grade.

If homework is given, it must have some basis in the teacher's objectives: drill, concept fixing, concept stimulating, or creative action. When the teacher's intent is to elicit creativity, i.e., design an experimental setup to test

a prediction, then grading would properly be based more on the process the student used than on the particular result obtained. The *how* is more *important* than the *what*.

Observation through interview. All students should have a talk with their teacher. This is a guidance function and is not rated. It helps the teacher help the student by providing insight into the student's problems. A good talk with students will often shed light on difficulties and skills, as well as hopes and aspirations.

Records of such observations (comments, aspirations, home environment, hobby interests, club work) may be kept in cumulative envelopes where pertinent records of the student are kept. When all teachers make such observations, a fairly useful picture of the student may be obtained.

The cumulative record. From the time a student enters a school to the time of his leaving, a cumulative record might be kept; it is very valuable. In it are kept such items as:

intelligence tests
Kuder preference ratings
Science Research Associates tests of Primary Mental Abilities
records of extracurricular work
records of interviews
achievement test scores (e.g., *Iowa Tests of Educational Development*)
school record
essays such as: "What I'd Like to Be," "My Future," "The Subjects I Like Most," "The Subjects I Like Least," "My Hobbies"
complaints by teachers
commendation by teachers

A cumulative record such as this helps the teacher assess his students' abilities; it enables the student to appraise his own growth; it enables a parent to scan the progress of a son or daughter; it is a base for guidance, diagnosis, and recommendation.

Testing

"Subjective" and "objective" tests. A so-called objective test is actually one which is *scored* objectively and quickly. It necessitates just as much judgment (subjective) as an essay test, but the judgments are made in selecting and wording the items *before* the test is given, rather than in scoring afterwards. *But this does not eliminate the need for thoughtful sagacity and careful planning.* We have stressed the necessity of judgments in evaluation, because sometimes all of us would like to escape that responsibility. But this is part of the job of the teacher or any other expert. Who is better qualified than he to make the inevitable judgments? (In Chapter 20 we present some materials that we hope will assist somewhat in increasing your skill in this difficult operation.)

Although most discussions on testing stress the use of objectively scored tests, the essay still has major uses in instruction and evaluation. Like all other devices, it has advantages and limitations. An essay question requires the student to create his answer. He must recall, select, organize, argue, and conclude without many clues. These are all operations we wish the students to do well.

Irrespective of the form in which a test item is cast, sometime between the inception of the item and its final scoring certain difficult decisions must be made. These include the particular word pattern with which the student is faced. These also include a decision as to what answers will be acceptable and to what degree. Too often essay questions are written quickly without consideration of their meaning to the students. Vagueness and ambiguity oblige the student to guess what is desired. Sometimes he guesses entirely wrong through little or no fault on his part. We hardly wish to score him for his ability to guess what the instructor wanted. To prevent this difficulty, essay questions should be worded carefully and checked in advance for meaning, perhaps casually during a class discussion. Perhaps the time allowance for each item can be given as well.

Notice the clarity and point scoring of this essay question:

> Atomic energy has had its use during wartime. Now plans are being made for its use during peacetime. What are these uses?
>
> In your discussion be certain you develop the uses of atomic energy in industry, in medicine, and in agriculture (6 points).
>
> Also in your discussion be certain to include the dangers involved (2 points) and methods of overcoming these dangers (2 points).

To the reader: The students will have had opportunity to discuss in class what point scoring means, e.g., one idea developed in a short paragraph for each point.

Note that provision has been made for adequate scoring. This has been done by dividing the essay question into parts, specifying the score of each part and, in that way, indicating the extent of time to be spent in answering. Note, too, that the directions are specific for each part. Essay questions can be scored with some degree of reliability if provisions such as the above are made. If, however, the question were stated as below, adequate scoring would not be so easy. Often a student, not knowing the particular answer sought, will "write around" the question hoping that possibly some credit will be given.

> Atomic energy has had its use during wartime. Now plans are being made for its use during peacetime. What are these uses? (10 points)

The difficulties of scoring essay questions are well known.[7] A single

[7] See, for example, Claude M. Fuess, *The College Board: Its First Fifty Years*, Columbia U. Press, N. Y., 1950.

Earle G. Eley, "The Experiment in General Composition," *College Board Review*, No. 15, Nov. 1951.

Richard Pearson and Earle G. Eley, "Should the General Composition Test Be Continued?" *College Board Review*, No. 25, Winter 1955.

reader may change his standards between the first and last paper read. The story of one competent examiner unwittingly giving a failing grade to the "model answer" prepared by another competent examiner may be apocryphal, but it contains much truth. To reduce this variance between papers and readers, a "standard answer," or outline of such an answer, can be prepared in advance as a continuing criterion. This will somewhat reduce the unreliability of scoring. It constitutes the first step toward the creation of objectively scored essay test items.

For years the College Entrance Examination Board and the Educational Testing Service have been investigating the sources of unreliability in scoring essays. As might be expected, they found that different readers assigned greater weights to different aspects of the essay. For English essays they isolated five major components: Mechanics, Style, Organization, Reasoning, and Content. When the readers scored essays on each of these subdivisions, somewhat greater reliability of scoring resulted. In addition, such subscores provide a profile of the student's abilities.

Irrespective of the potential values of essay questions and the devices that increase their reliability of scoring, their writing and especially their reading takes a long time. Within the testing time available, only a few essay questions can be answered. As a consequence we can sample only a small range of the student's knowledge and concepts. Probably each teacher recalls some instance when he did well on an essay test because he happened to be well informed on the particular questions asked, but realized that he would have scored much lower on other equally likely questions.

Conscientious reading and scoring of each paper, with the addition of marginal notes to help the student, will probably take a teacher from one-fourth to one-third of the time it took the student to write it. A one-hour essay examination of 150 students may require from 40 to 50 hours of reading. This is a sizable amount of time which teachers do not often have available, especially when grades from final examinations are to be reported quickly. For these reasons the quick-scoring or objective-scoring form of test has become popular.

We are all familiar with the inherent difficulties of objectively scoring essays and essay questions in tests. After describing one means of examining essays, Dyer made the following comments (italics ours): [8]

> The foregoing procedure is scarcely as clean-cut and precise as applying a yardstick. It depends heavily on personal judgments—judgment with respect to the questions that shall go into the test and judgments with respect to the merit of the essays. The fact that subjective judgment is a large element in the process is, however, nothing against it. Indeed, any attempt to minimize the effect of judgment in a process of this kind will by so much minimize the meaning of the results, for that which we call achievement is, in the last analysis, only somebody's judgment of what somebody else does. We fool ourselves, and our students, when we suppose that by resorting to "objective" tests we are obtaining a measure of

[8] Henry S. Dyer, *General Education in Science*, ed. by I. B. Cohen and F. G. Watson, Harvard U. Press, Cambridge, 1952, p. 200.

performance that is objective in the sense of being independent of human judgment. It is healthier to realize that *the problem is not to eliminate judgment from the process, but to keep the judgments we make relevant to our purposes.*

By implication we have indicated some of the advantages and disadvantages of objective tests. Because they contain many items, they oblige the student to respond to a wide variety of problems. We get a better sample of what the student can do. Because they often require the selection of a specific "best answer" from among others, they are readily and accurately scored.

Critics of objective questions properly point out that often they do not put a premium on creative work by the student. Yet often such criticisms are illustrated by only the simplest forms of objective items. These items *can* be written in such a manner that considerable knowledge must be recalled and careful judgments made, even arithmetical operations performed, before an answer can be selected. Consider this item:

> It is a Massachusetts State requirement that an automobile be capable of being stopped within a distance of 25 feet when moving with a velocity of 20 miles per hour (about 30 feet per second). Use Galileo's equations to show that the required average acceleration in feet per second is: (1)18 (2)9.0 (3)4.5 (4)1.2.

The student is obliged to recall Galileo's equation, $2ad = v^2$, or to derive it from the other two, to substitute the numbers properly and derive an approximate answer, and then choose the best answer offered. For the particular class to which this item was given, it was moderately difficult and highly discriminating between those with top scores and bottom scores on the entire test.

The item could have been made more difficult by obliging the student to recall the numerical value of acceleration (g) and express his answer in terms of g:

$(1)\frac{3}{4}g\ (2)\frac{1}{2}g\ (3)\frac{1}{4}g\ (4)\frac{1}{10}g.$

It could also have been modified so that the student indicated which of various equations would be used to get an answer:

$(1) v = at\ \ (2) 2ad = v^2\ \ (3) d = \frac{1}{2}at^2\ \ (4) d = vt.$

A great advantage of objective tests, often overlooked by teachers, is the opportunity to insert various forms of erroneous answers which will reveal the errors in knowledge and reaction of the students. Some items of this type are presented when we consider diagnosis (p. 404).

Objective items and reading skills. The form of items used in the central, and most discriminating, section[9] of the tests of the Nation-wide Science Talent Search involves a fairly long statement followed by four to six test items of increasing difficulty. Some teachers object that this form of presentation, used in other tests as well, is actually a reading test. Must we conclude that in

[9] F. G. Watson, "Analysis of a Science Talent Search Examination," *The Science Teacher*, 21, 274, 1954.

science one is not supposed to know how to read? We doubt this. Certainly one of the major skills of the scientist is knowing what and how to read. Reading in science involves standards different from those of literature: evidence is clearly stated and the limited conclusions drawn must be justified by the material presented.[16] Therefore such test items seem most appropriate in a science test. The technique and care involved in preparing them are described briefly in the next chapter.

Evaluation for achievement

Achievement can be appraised through any operation in which the reactions of the students can be noted and judged; this includes teacher-made and so-called standardized tests. Both are useful and both are used in many school systems. The type of achievement and the level of difficulty in a teacher-made test can be set to match the focal intents and students. But some basis of comparison with other schools and students, as provided by the published tests, is also useful.

Tests made locally are commonly used to evaluate achievement in the learning of certain information and applications. If the material or skills are considered to be very important, the test may be one on which the teacher expects every student to achieve perfection. This type of test reveals those who are not up to some standard of expectation. Of course, the standards must be set realistically in terms of the particular students. Science-shy and science-prone groups will require quite different tests. Basically these provide the student with an inventory of his accomplishments.

Other tests are used to determine general achievement. Ordinarily, no student will have a perfect paper; otherwise we have not found how he would react to even more difficult questions. This second test pattern has a higher ceiling of difficulty and should distribute the students' scores over a sizable range. For practical purposes of morale a few easy items, many about average, and a few very difficult ones should be chosen. Generally the *average* score for a class would be between 60 and 70, out of a possible 100, on such a test. In Chapter 20 we consider the preparation of such tests.

Standardized achievement tests are made for wide usage in schools with varied curriculums. Therefore, the selection of standardized achievement tests should be done thoughtfully. These tests generally are highly *reliable* (more so than perhaps a teacher-made test can be), but they may or may not be *valid* for your purposes (as your own test is likely to be). You can determine this fairly well if you have behavioral objectives which can be compared to the operations required by the test items. Information about the reliability of the test is normally supplied with a sample copy from the publisher. In addition, attention must be given to the basis on which the test was stand-

[16] Such skills do not come automatically to the student; they must be taught. The science teacher is necessarily a teacher of reading *in science*.

ardized: how many children were tested, in what schools or states they were tested, and, especially, when this was done. As the amount of science increases in the school program, test norms established some years ago will no longer be applicable, everyone will have classes "better than average." Many of the achievement tests in science were made some years ago and may not use material appropriate for your classes. Considerable information and critical comments about available tests can be found in *The Fourth Mental Measurement Yearbook* [11] and in reviews in journals such as *The Science Teacher.*

"Cheap" and "expensive" recall

Before the day of the objective test, there was the day of the stern taskmaster. Each day there was the recitation with the students confident or quaking as they were called upon to recite. Do you remember?

Jones, what is mitosis?
Brown, define electromotive force.
White, name the simple machines.
Smith, go to the board and write the equation for the preparation of bromine.

The student was asked to reproduce, recall, or remember what he had "learned" before he entered the class. Many times he was asked to recall what had been specifically assigned; the emphasis was generally on memory, while reasoning, critical thinking, the ability to see relationships were not stressed. This was the "cheapest" type of recall. Either one recalled or one didn't; those who did it best were most successful, they received the highest grades.

Nowadays, such recitation is generally replaced by the quiz, short or long. Quiz items which stress "cheap" or "expensive" recall follow a pattern somewhat like these:

1. True-false. In this type of item, the student indicates by T or F whether the statement is *true* or *false*. Thus:

> ____ The greater the amplitude of a sound wave, the louder the sound.

2. Modified true false. The item above can be made more "expensive" to recall by adding these instructions:

> The following items are either *true* or *false*. If the statement is true, mark T in the appropriate place; if false, replace the underlined word with a word which makes the statement true.
> ____ The greater the <u>amplitude</u> of a sound wave, the louder the sound.

It seems clear that greater thought needs to be brought to bear to answer item 2 than item 1. We say that item 2 is more "expensive," because greater

[11] Edited by O. K. Buros, Rutgers U. Press, New Brunswick, N. J., 1953, fifth yearbook in press

time and energy is spent in thought, to get similar credit. Furthermore, it affords less opportunity for guessing.

From a study of these two examples we derive an essential difference between "cheap" and "expensive" recall. Recall is made more expensive as the amount of energy or time spent in thought is increased. This can be done by increasing the number of things a student must remember, and the number of manipulations a student must perform before he gets the "right" answer.

Notice how more thought and judgment is progressively required in this series of multiple-choice items:

1. The substance in red blood cells that picks up oxygen in the lungs is: (a) chlorophyll (b) hemoglobin (c) sodium carbonate (d) water.

2. The substance in red blood cells that picks up oxygen in the lungs is: (a) chlorophyll (b) hemophyll (c) chloroglobin (d) hemoglobin.

3. Match the terms in column A with their appropriate meaning or definition in column B. Place the letter of the correct answer in the space provided.

A	*B*	
a. hemoglobin	47. a red substance used in respiration	____
b. nitrogen	48. a green substance used in photosynthesis	____
c. cellulose		
d. oxygen	49. a gas carried to cells by hemoglobin	____
e. carbon dioxide		
f. chlorophyll	50. a gas used in food making in photosynthesis	____

Item 1 is clearly cheap recall; the distracters (wrong answers) are quite obviously wrong. Item 2 involves slightly more expensive recall; the student is forced to make a sharp judgment between terms very much alike. Knowing half of the right word is no help! And in item 3, more answers are supplied than are required; this tends to reduce guessing, and eliminates the possibility of a "free" fourth answer, once the first three are known.

There are many more kinds of *recall* items, of the so-called formal objective type, which may be used. For instance, a diagram may be inserted for labeling, structures may be required to be drawn in place (e.g., wires in a parallel or series circuit), but essentially they all require *recall of facts.*

Many collections of items testing recall which the reader may obtain, some for the asking, are cited in Chapter 20, which is essentially an expanded "Excursion" for this chapter.

Notice that we have made no comment about the validity of these sample items. A test item is valid or not for a *particular purpose.* Unless this is stated, we can make no judgment. Item 1 just stated here indicates, with some degree of validity, whether the student knows what the red stuff in blood is called. It does not determine whether he understands respiration and circulation; indeed, it almost tells him about them. It does not reveal his attitudes towards physiology, his ability to handle problems of health, or his ability in concept attainment. If we wish to evaluate these latter aspects of his learning, we must

use other, and probably different, types of test items; this one obviously is not valid for these purposes.

More than recall—skills

We teach for more than recall of facts: in science, we are determined that youngsters gain certain skills. We should be disturbed if a youngster went through biology without learning how to use a microscope, chemistry without learning how to handle a burner or a test tube, physics without learning how to connect wires in series. Science has its practical side—its skills as well as its knowledges.

No doubt the reader has given the kinds of tests itemized below. These have high face validity (they measure directly) and generally high reliability.

1. *In physical science.* Students have been studying a unit on the nature of the earth. They have been identifying rocks. When they feel certain they can identify them, they are given a "practical" examination. The rocks are placed before them and they are asked to name them (with proper precautions to avoid collaboration).

2. *In biology.* Students have been studying mitosis in onion root. During a laboratory exercise, the teacher comes to each with a demonstration ocular (an ocular with a pointer); he inserts it into the student's microscope, points it at that part of the field that he then asks the student to identify.

3. *In general science.* Students have been studying circuits; they have seen them demonstrated. The teacher then gives them materials (bulb, insulated wire leads, plug; the students bring their own screw drivers). Each student is supposed to wire the lamp so that it lights when inserted into a socket.

4. *In chemistry.* Students have finished studying the halogens. They are given "unknown" solutions, salts of bromine, chlorine, and iodine. (One unknown contains only distilled water.) They are asked to identify the unknowns using replacement tests.

5. *In physics.* Students are asked to determine the density of a block of material using Archimedes' principle.

These items are not only valid, but they are reliable and interesting as well. Two major classroom problems, however, are those of maintaining security between classes and of preventing collaboration. This can be done in various ways depending on the situation. For instance, in identifying a series of specimens, students might move at a given signal from numbered specimen to numbered specimen. Or different specimens might be used for different pupils. With paper-and-pencil tests, alternate forms can be used.

Some teachers will wonder whether the identification of rocks or organs is a skill, whether it is not mainly another form of recall. Certainly recall is involved, but more than recall is required. It is a skill because it involves practice (handling of rocks, etc.). Probably a skill involves "doing" as well as "thinking." Possibly the following might more aptly test skills.

1. Given a blue copper sulfate solution, students are asked to deliver to the instructor 1 cc of pure, clear water prepared from it. (Students must set up a simple distilling apparatus: a test tube and delivery tube for heating the solution, another test tube immersed in cold water to catch the water.)

2. Students are asked to dissect out the brain of a preserved frog.

3. Given an unknown concentration of HCl (dilute), students are asked to determine its strength using 0.1*N* NaOH. (Alternate students are given different concentrations of HCl.)

4. Given a graph of the quantity of a catalyst against the rate of a reaction, students are asked to extrapolate the curve to a given point. (Extrapolation and interpolation are important skills.)

A scoring scale for use with such tests can be tried out before being made final. Or perhaps the students would assist in assigning values to the various operations. Possibly in item 3, an error of 20% might be scored as 75 points or a grade of C, 10% error as 85 or B, 5% error as 95 or A, and 2% error or less as 100 or A+. Each instructor will choose his own scale of grades for practical tests depending upon the abilities of his students. In any event, it is our experience that students prefer to be graded on tests of more than their ability to recall. (Note: these tests can also be used for diagnostic purposes, p. 404.)

More than recall and skills—reasoning

Testing for recall and skills is not enough. You can also test youngsters for their ability to reason, to reflect, and to draw defensible conclusions. Of course, if you plan to test for these abilities, you will handle your class in such a manner that the students practice these operations frequently and know that they are important to you. You will teach differently if you expect youngsters to use the facts they learn for building concepts and conceptual schemes (see Chapter 6).

Some examples of test items that emphasize reflection and thought appear below. Scores on tests consisting of items like these correlate strongly with I.Q. scores, but interesting differences may occur with individual students. Note this progression in demand upon the student: [12]

1. A body that emits its own light is called a _____ body.

2. The focal length of a lens is the distance between the center of the lens and the _____.

3. To produce an enlarged virtual image with a convex lens, the object distance should be (1) less than 1*f* (2) between 1*f* and 2*f* (3) greater than 2*f*.

4. The lamp in a parallel ray projector should be _____ inches from the lens where the latter has a focal length of 8 inches.

The validity of such reasoning items may always be questioned. However, a simple procedure may help convince the skeptic of the nature of the reasoning involved. Let us examine *what the student must do* in responding to each of the four items:

---

[12] Taken from various examinations in physics, Board of Regents, New York State.

1. Remember a term (radiant or luminous) defined by the conditions given. If he does not remember the term, there are few clues or associations (concepts) through which he can search for a satisfactory answer. This is cheap recall.

2. Remember a term (focal point). This may be associated with demonstrations, laboratory work, or diagrams with which the student is familiar. The item requires a definition (of focal length), but it can be associated with observable phenomena which may provide clues to assist recall. This is more expensive recall.

3 Recall the meaning of "virtual image," "convex lens," "object distance," "If," etc. The relationship between these components is needed. It may be recalled directly. If not, it may be reconstructed on the basis of experience (laboratory, demonstration). The response requires the recognition of which among three general positions or classes of location is appropriate. Still more expensive.

4. Recall the meaning of "parallel ray projector" and "focal length" and the specific (numerical) relation between the focal length in inches and the positions which produce parallel rays. If recalled, general properties of lens systems can be used to solve the problem. A specific numerical answer is required.

These four items illustrate a progression from cheap recall, to expensive recall, to recognition of a relationship, and to the exact statement and use of a relationship. The last two items test not only recalled knowledge but reasoning as well. However, the reasoning depends, as reasoning always does, upon prior knowledge and experience. A student who has not studied the material or had experience with it is not likely to exhibit the proper response.

Evaluation for diagnosis

To know that a student has or has not attained certain knowledge and skills is interesting, but in order to help the students we need to know specifically where each student "went wrong," what blocks to learning are acting in each pupil. For this we need, in addition to the daily test of class behavior and observation, diagnostic tests. They provide information about *all* the students in the class, including the quiet ones who are too often underestimated or overestimated because of a lack of knowledge about them. Unfortunately we are not aware of any tests in science that can be purchased for such diagnostic use. General tests like the Primary Mental Abilities Test are helpful, but are not specific to the materials and operations of science. There is, however, a considerable literature about such tests which would serve as illustrations to an interested teacher.

One point must be stressed early: for each attribute to be described, *several*, usually five or more, items will be required. The desired response to only a single item might be guessed correctly or failed through the action of a

particular distracter. The score on a block of items involving the same operation has some trustworthiness and can be totaled for each student. Then you have some measure of the behavior of each child *on this particular operation*. Such subtests can provide a profile of the strengths and weaknesses of each pupil. Since it is the pupils whom we hope to assist, they should be informed of their profiles and encouraged to work deliberately on their greatest weaknesses. Such tests are not likely to be desired as a basis for assigning grades, but they will be of great value to the teacher as he plans and runs his class. This type of test can also be useful for predictive purposes (see below).

One major attempt to develop test items aimed at evaluating the way of the scientist and the use of the skills of the scientist was made in the Eight-Year Study. The third volume of the report of that study presents in detail the rationale and nature of the tests: [13]

BASIC ASSUMPTIONS

In the first place, it was assumed that education is a process which seeks to change the behavior patterns of human beings. It is obvious that we expect students to change in some respects as they go through an educational program. An educated man is different from one who has no education, and presumably this difference is due to the educational experience. It is also generally recognized that these changes brought about by education are modifications in the ways in which the educated man reacts, that is, changes in his ways of behaving Generally, as a result of education we expect students to recall and to use ideas which they did not have before, to develop various skills, as in reading and writing, which they did not previously possess, to improve their ways of thinking, to modify their reactions to esthetic experiences as in the arts, and so on. It seems safe to say, on the basis of our present conception of learning, that education, when it is effective, changes the behavior patterns of human beings

A second basic assumption [was that] the kinds of changes in behavior patterns in human beings which the school seeks to bring about are its educational objectives. The fundamental purpose of an education is to effect changes in the behavior of the student, that is, in the way he thinks, and feels, and acts. The aims of any educational program cannot well be stated in terms of the content of the program or in terms of the methods and procedures followed by the teachers, for these are only means to other ends. Basically, the goals of education represent these changes in human beings which we hope to bring about through education. The kinds of ideas which we expect students to get and to use, the kinds of skills which we hope they will develop, the techniques of thinking which we hope they will acquire, the ways in which we hope they will learn to react to esthetic experiences—these are illustrations of educational objectives.

A third basic assumption [was that] an educational program is appraised by finding out how far the objectives of the program are actually being realized. Since the program seeks to bring about certain changes in the behavior of students, and since these are the fundamental educational objectives, then it follows that an evaluation of the educational program is a process for finding out to what degree these changes in the students are actually taking place.

The fourth basic assumption was that human behavior is ordinarily so complex that it cannot be adequately described or measured by a single term or a

[13] By permission from *Appraising and Recording Student Progress*, by Eugene R. Smith, Ralph W. Tyler, and the Evaluation Staff, Vol. 3 of Progressive Education Association, *Adventure in American Education*, pp. 11-14. Copyright, 1942. McGraw-Hill Book Company, Inc., N. Y.

curricula and, as far as possible, of a nonrestrictive nature. That is, major attention was given to appraisal devices appropriate to a wide range of curriculum content and to varied organizations of courses. Much less effort was devoted to the development of subject matter tests, since these assumed certain common informational material in the curriculum.

The eighth basic assumption was that the responsibility for evaluating the school program belonged to the staff and clientele of the school.

These basic assumptions show that one of the primary objectives of the Eight-Year Study was to determine the extent to which students could reason. Three aspects of clear or critical thinking selected for emphasis were:

1. Ability to interpret data.
2. Ability to apply principles of science.
3. Understanding the nature of proof.

We shall give examples of each of these in turn. While all of these might be included within a single rubric like "reflective thinking," for clarity of appraisal and diagnosis this clean cut separation is desirable (see, for example, the definitions of Burke, p. 103).

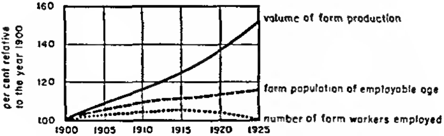
Ability to interpret data

The test on Interpretation of Data (Test 2.52) from which the following example [14] is taken contained ten such items based on different subject areas.

On this item students are directed to place the suitable number (1, 2, 3, 4, or 5) identifying their judgments opposite the number of the statement, or to blacken an appropriate place on a score sheet.

These data alone:

(1) are sufficient to make the statement true.
(2) are sufficient to indicate that the statement is probably true.
(3) are not sufficient to indicate whether there is any degree of truth or falsity in the statement.
(4) are sufficient to indicate that the statement is probably false.
(5) are sufficient to make the statement false.



Problem 1:

This chart shows production, population, and employment on farms in the United States for each fifth year between 1900 and 1925.

[14] Eugene R. Smith, Ralph W. Tyler, and the Evaluation Staff, *op. cit.*, pp. 52-53.

Statements

1. The ratio of agricultural production to the number of farm workers increased every five years between 1900 and 1925.

2. The increase in agricultural production between 1910 and 1925 was due to more widespread use of farm machinery.

3. The average number of farm workers employed during the period 1920 to 1925 was higher than during the period 1915 to 1920.

4. The government should give relief to farm workers who are unemployed.

5. Between 1900 and 1925, the amount of fruit produced on farms in the United States increased about fifty per cent.

6. During the entire period between 1905 and 1925, there was an excess of farm population of employable age over the number of people needed to operate farms.

7. Wages paid farm workers in 1925 were low because there were more laborers than could be employed.

8. More workers were employed on farms in 1925 than in 1900.

9. Since 1900, there has been an increase in production per worker in manufacturing similar to the increase in agriculture.

10. Between 1900 and 1925, the volume of farm production increased over fifty per cent.

11. Farmers increased production after 1910 in order to take advantage of rapidly rising prices.

12. The average amount of farm production was higher in the period 1925 to 1930 than in the period 1920 to 1925.

13. Between 1900 and 1925, there was an increase in the farm population of employable age in the Middle West, the largest farming area in the United States.

14. Farm population of employable age was lower in 1930 than in 1900.

15. The production of wheat, the largest agricultural crop in the United States, was as great in 1915 as in 1925.

This block of test items can provide considerable information about the ability of the student to operate effectively in science. Smith and Tyler report that: [13]

> These interpretations involve the following types of behaviors: comparison of points of data, recognition and comparison of trends, judgments of cause, effect, purpose, value, analogy, extrapolation, interpolation, and sampling.
>
> The types of relationship involved in the interpretations which the students are asked to judge were distributed among the five response categories. [About ten per cent were *true*, about twenty per cent were *probably true*, about forty per cent were supported by *insufficient data*, about twenty per cent were *probably false*, and about ten per cent were *false*.] Within each test exercise the interpretations were arranged in random order.

Pupil responses to items of this form were scored in terms of: *general accuracy*, *caution*, *beyond data*, and *crude errors*. The scoring key, devised with the assistance of a jury, is shown in Table 19-2.

General accuracy means agreement between the student's response and the judgments of the jury. For a number of items of this type, the total responses are counted in cells *a*, *g*, *m*, *s*, and *y*. This number is then expressed as a percentage of the total number of possible correct responses.

[13] *Op. cit.*, pp. 48-50.

TABLE 19-2 How scores are derived *

		Jury key				
		True	*Probably true*	*Insufficient data*	*Probably false*	*False*
Student response	*True*	accurate a	beyond data b	beyond data c	crude error d	crude error e
	Probably true	caution f	accurate g	beyond data h	crude error i	crude error j
	Insufficient data	caution k	caution l	accurate m	caution n	caution o
	Probably false	crude error p	crude error q	beyond data r	accurate s	caution t
	False	crude error u	crude error v	beyond data w	beyond data x	accurate y

TABLE 19-3 Sample data sheet *

Seven students from a group of 69; all scores are percentages

	ACCURACY							
Student	*General accuracy*	*Probably T or F*	*Insufficient data*	*True-False*	*Omit*	*Caution*	*Beyond data*	*Crude errors*
PEGGY	31	20	30	32	0	13	60	32
JOSEPH	71	66	69	71	0	20	23	7
WILLIAM	64	65	54	68	0	7	33	14
HOMER	51	18	74	32	0	53	22	10
ANDREW	71	74	60	78	0	6	33	8
GEORGE	47	11	60	73	0	41	33	8
FAYE	57	46	53	73	0	21	37	11
GROUP MEAN OF THE 69	50	42	45	60	1	22	43	14

* By permission from *Appraising and Recording Student Progress*, by Eugene R. Smith, Ralph W. Tyler, and the Evaluation Staff, pp. 54, 57. Copyright, 1942. McGraw Hill Book Company, Inc., N. Y.

Discrimination on *probably true* and *probably false* items is found by counting the responses in cells *g* and *s* and comparing these with the total of desired responses in these categories. Agreement on *insufficient data* appears from the number of responses in cell *m* compared to the total correct in that category. Similarly, the agreement with *true* and *false* conclusions is found by counting the responses in cells *a* and *y*, respectively, and comparing to the number correct in those cells.

Similarly going *beyond the data* (overgeneralizing or being too optimistic) is shown by a count of responses in cells *b, c, h, r, w, x*. *Caution* is appraised by a count of responses in cells *f, k, l, n, o, t*. *Crude errors* are also counted and *omissions* noted for each student.

How tests such as these can be used to provide a profile of the operating attributes of students is illustrated in Table 19 3.

Now we have available evidence to support what we probably observed in class. Peggy is very low in general accuracy; she made many crude errors, and was "gullible" by frequently going beyond the data. She needs help in making fine distinctions and not acting as though every alternate was either "right" or "wrong." Homer is well-informed (few crude errors) but is very cautious. He does not go beyond the data often, but tends to respond that the data are insufficient for any conclusion. He too can be helped. George has a similar profile. Andrew is a promising boy who goes beyond the data sometimes, but less than the average of the group.

Information such as this (always, of course, from more than one test item) can greatly help a teacher see the individual characteristics of his pupils and work with each on his weaknesses. The students also should have a report on their characteristics, because teacher and student are working together consciously to bring about changed behavior. A similar test given at the end of the year will show what success has been attained. Also, other teachers having these same children later can see the records and be alerted to the particular limitations affecting each student.

There are many examples of this type both in the volume by Smith and Tyler and elsewhere.[16]

Ability to apply principles

In this test,[17] the correct responses are included in brackets.

> Tests following the general form below were constructed for the areas of chemistry (Form 1 31), physics (Form 1.32), biology (Form 1.33), and general science (Form 1.3a).*
>
> * A junior high school test, Form 1 3j, which uses a somewhat different and less complex technique was also constructed.

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[16] National Society for the Study of Education, *Forty-Fifth Yearbook*, Part 1, *The Measurement of Understanding*, U of Chicago Press Chicago, 1946

L E. Raths, "General Education in Science," *Educational Research Bulletin*, Ohio State University, *17*, 85, 1938.

[17] Eugene R. Smith, Ralph W. Tyler, and the Evaluation Staff, *op. cit.*, pp. 91-93.

A sample problem taken from Form 1.3a is given with the directions and key.

PROBLEM

The water supply for a certain big city is obtained from a large lake, and sewage is disposed of in a river flowing from the lake. This river at one time flowed into the lake, but during the glacial period its direction of flow was reversed. Occasionally, during heavy rains in the spring, water from the river backs up into the lake. What should be done to safeguard effectively and economically the health of the people living in this city?

Directions: Choose the conclusion which you believe is most consistent with the facts given above and most reasonable in the light of whatever knowledge you may have, and mark the appropriate space on the Answer Sheet.

CONCLUSIONS

[V] A. During the spring season the amount of chemicals used in purifying the water should be increased. [Supported by 3, 7, 10, 12][18]

B. A permanent system of treating the sewage before it is dumped into the river should be provided. [Consistent with 5, 8, 12]

C. During the spring season water should be taken from the lake at a point some distance from the origin of the river. [Consistent with 12, 14]

Directions: Choose the reasons you would use to explain or support your conclusion and fill in the appropriate spaces on your Answer Sheet. Be sure that your marks are in one column only—the same column in which you marked the conclusion.

REASONS

[False analogy]	1. In the light of the fact that bacteria cannot survive in salted meat, we may say that they cannot survive in chlorinated water.
[Irrelevant]	2. Many bacteria in sewage are not harmful to man.
[Right principle]	3. Chlorination of water is one of the least expensive methods of eliminating harmful bacteria from a water supply.
[Ridicule]	4. An enlightened individual would know that the best way to kill bacteria is to use chlorine.
[Wrong, supporting B]	5. A sewage treatment system is cheaper than the use of chlorine.
[Authority]	6. Bacteriologists say that bacteria can be best controlled with chlorine.
[Right]	7. As the number of microorganisms increases in a given amount of water, the quantity of chlorine necessary to kill the organisms must be increased.
[Wrong, supporting B]	8. A sewage treatment system is the only means known by which water can be made absolutely safe.
[Assuming conclusion]	9. By increasing the amount of chlorine in the water supply, the health of the people in this city will be protected.
[Right]	10. Harmful bacteria in water are killed when a small amount of chlorine is placed in the water.
[Teleology]	11. When bacteria come in contact with chlorine, they move out of the chlorinated area in order to survive.
[Right, supporting A B C]	12. Untreated sewage contains vast numbers of bacteria, many of which may cause disease in man.

[18] Answer to another part of the test; see below.

[Irrelevant]	2. The liquid which is absorbed most readily by the skin is the most effective in softening the hands.
[B]	3. To be absorbed by the skin, a hand lotion need not pass through the skin.
[Irrelevant]	4. Hand lotions are of doubtful value.
[A C]	5. The faster a liquid drips through filter paper, the faster it will be absorbed by the human skin.
[A C]	6. The pores of the skin are quite similar to the little holes between the fibers of filter paper.
[A]	7. Since each bottle was given a thorough shaking, the results for each lotion were typical of the performance of the lotion in that bottle.
[B]	8. The "pores" in filter paper are constructed quite differently from the "pores" in the human skin.
[Irrelevant]	9. The experiment was probably intended to make sales for some cosmetics manufacturer.
[B]	10. Although drops of a liquid appeared in the water glass, certain ingredients of the first lotion may have been retained by the filter paper.
[Irrelevant]	11. The speed with which a lotion drips through filter paper is no indication of its effectiveness in softening the skin.
[B]	12. Water will penetrate filter paper but is not absorbed by the skin.
[Irrelevant]	13. The obvious way to test the five lotions is to try them on the hands of a large group of people.
[A]	14. The amounts of lotion placed on each piece of filter paper were very nearly the same.

II. *Directions: Select from the statements already marked under A (the supporting statements) those which you would challenge because you are not convinced they are true enough to be used in supporting the underlined conclusion. Blacken the space under C opposite the number of each such statement.*

III. *Directions: Conclusions A, B, and C are stated below. Choose the one which seems to you to be most consistent with your analysis of the situation described in the problem. In the block at the top of the answer sheet, blacken the space A, B, or C to indicate the conclusion which you choose.*

CONCLUSIONS

[V] A. This experiment does not help in deciding which one of the hand lotions would be most readily absorbed by the skin.

B. The experiment suggests that the first brand of hand lotion is absorbed by the skin more readily than any of the others, but the experiment would have to be repeated several times.

C. The experiment shows that the first brand of hand lotion is absorbed by the skin more readily than any of the others.

IV. *Directions: Hand lotions are commonly used to replace the oils in the outer layers of the skin which are lost through excessive exposure, washing, and other causes. Hence, it may be less important to study the extent to which a lotion penetrates the layers of the skin than to study its effect upon the surface of the skin. The statements presented below describe some activities which have been suggested to study the effectiveness of a hand lotion in keeping the skin soft in the absence of an adequate supply of natural skin oils. Select all statements that describe activities which you think would help in studying this effect of a hand*

lotion upon the skin. Blacken the space under A opposite the number of each such statement. In this part of the test, your decision about a statement should not be influenced by whether you believe the activity described could actually be carried out.

STATEMENTS FOR IV AND V:

[A B]	15. Secure a description of the structure of the human skin.
[Irrelevant]	16. Find out the names of the companies which manufacture each of the brands of hand lotion used in the experiment
[A]	17. Make a precise laboratory analysis of each of several brands of hand lotion to find out the amounts and properties of its principal ingredients, such as vegetable oils, water, etc.
[Irrelevant]	18. Repeat the experiment several times with the same five lotions and under exactly the same conditions
[A B]	19. Set up an experiment in which ten boys and ten girls apply a hand lotion to one hand and no hand lotion to the other hand once each day for a month, and compare the results.
[Irrelevant]	20. Send out a questionnaire to a large number of users of hand lotion to find out which brand is most popular.
[A B]	21. Use hand lotions regularly on several parts of the body and compare the results
[A]	22. Set up an experiment to compare the natural skin oils to the oils contained in hand lotions.
[Irrelevant]	*23. Compare the absorbing power of filter paper* and human skin.
[A B]	24. Look for published information about some of the good and bad effects of using different brands of hand lotion.

V. *Directions: Select from the statements already marked under A only things which you think you or your class in high school could actually carry out. Blacken the space under B opposite the number of each such statement.*

A brief look at the "practical" side

The test items we have presented above are exceedingly interesting. They demand thought or reasoning or judgments or reflective thinking—whatever you wish to call it. But tests of this type on the analysis of data, application of principles of science, or the nature of proof are not widely used.

Most of the tests available for purchase or made by teachers have as their primary purpose the testing of recall or application of principles in carefully selected problems. Essentially the testing pattern in science deals with recall, knowledge of principles, and application of principles within a restricted context.

Some of the major reasons put forward for not using tests on interpretation of data, general application of principles, and the nature of proof are:

1. Tests of this type are too cumbersome to make and to score. *Whether*

or not they are "too" cumbersome and time-consuming depends upon the importance you assign to these intellectual skills and their appraisal.

2. Tests of this type can be handled only by the more able students. *Is this contention supported by evidence? (We do not know. But if it is, would simpler tests for the same attributed behaviors be useful for diagnosis helpful to teacher and student alike?)*

3. The standardized or college entrance tests on which children are expected to succeed do not make use of items of this type. *Correct regarding test item form, but increasingly such tests are being aimed at the more complex mental operations. See page 420 for more on the College Entrance Board Examinations.*

Evaluating beyond recall, skills, and reasoning—attitudes

The attitudes involved in scientific work are not easily examined by paper-and-pencil tests. You would expect very low validity of items claiming to test for "honesty" or "open-mindedness" or "persistence." But this does not mean that we cannot appraise these attitudes. Remember that paper-and-pencil tests are used only as means of replacing the actual operation. We must assert the validity of the test items, whereas the actual performance has face validity.

In the total behavior and learning of the student in science, attitudes are very important. In fact, some of the studies on the identification of potential scientists appear to have gone astray because they were concerned only with the "academic" or intellectual abilities of the children as described through paper-and-pencil tests. The emotional and attitudinal components are certainly equally, if not more, important. Where and how can a teacher get first-hand evidence of attitudes?

Where else but in his classroom and laboratory? As children are faced with real problems, real frustrations (at least temporary ones), real evidence, and real conclusions, they react. Through their reaction patterns their attitudes stand clear. You can observe and record these on an anecdotal record form. The date and, briefly, the circumstances are useful too. They permit you to observe how the student grows or changes during his schooling. From such notes a profile of attitudes can be constructed as part of the child's description. Such records are, unfortunately, not common in the secondary school, but their desirability and use is apparent.

The terse observation that "education is what remains after what we learned has been forgotten" cannot be passed over lightly. What remains then will be the general attitudes toward certain types of conditions or subject areas. These will influence when and what actions, if any, will be taken. Often, as science teachers, we seem to give little concern to the student's attitudes toward science, which grow whether we desire this or not. Perhaps, through lack of concern for attitudes, we are defeating the major intentions of our instruction.

lotion upon the skin Blacken the space under A opposite the number of each such statement In this part of the test, your decision about a statement should not be influenced by whether you believe the activity described could actually be carried out

STATEMENTS FOR IV AND V:

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for example, among some 1,100 freshmen at Harvard about 500 secondary schools in all parts of the country and some foreign lands are represented.

Pressures for admission to the state universities have increased and will continue to increase in the years ahead. Already several such institutions are using these examinations to provide information to the admission officers.

The College Entrance Examinations are currently of two parts. The Scholastic Aptitude Test is widely used as a general measure of academic potentiality. It consists of two sections which yield "verbal" and "mathematical" scores. In addition, achievement examinations in three areas are required or requested by a number of colleges. These three achievement examinations, each an hour in length, may be chosen from a list of fifteen to eighteen subjects offered. Those in science are biology, chemistry, and physics. Two examinations in mathematics are also offered, intermediate and advanced.

The purpose of these examinations is to compare each student with the total group who took the examination on the same date. There are no national norms or year-to-year standards, although the Board does study the stability of the tests from year to year to provide their test makers with advice. Clearly there is no "passing or failing" on these examinations: they provide only a comparative scale. Furthermore, the significance attached to these scores in combination with other information varies considerably between colleges.[21]

Because considerable effort is invested in developing and pretesting the items comprising these tests, the tests are kept "secure." But their lack of availability to teachers and students is offset by a pamphlet about all the Board exams which describes and illustrates all their achievement tests now in use.[22]

The orientation of the tests is determined by committees of college and school teachers. From year to year the membership of these committees is changed so that a widely representative group of teachers advises the Board on the nature of the tests. Other committees assist by writing and appraising items which will be appropriate for the instruction offered in the secondary schools. Thereafter each item is pretested, and only about one in ten survives to be used in a test. This care makes the tests expensive, necessitates their security, and renders them fairly predictive.

Since great care is taken to make the tests valid in terms of the information and skills *normally* being considered in science classes, we wonder at the special emphasis placed upon the tests by certain teachers. Especially in some eastern secondary schools there is a brand of course known as a "college board course" which is often little more than a cram session. In these, quick recall is stressed to the *minimization of experience and comprehension or understanding.* The consequences of "cramming" or coaching for these examinations has been

[21] Henry S. Dyer and Richard G. King, *College Board Scores, Their Use and Interpretation No. 2,* College Entrance Examination Board, N. Y., 1955; available through Educational Testing Service, P. O. Box 592, Princeton, N. J., or P. O. Box 27896, Los Angeles, California; $1.50 per copy.

[22] *A Description of the College Board Achievement Tests,* College Entrance Examination Board, N. Y., 1956; available through Educational Testing Service, P. O. Box 592, Princeton, N. J.; fifty cents per copy.

Evaluation for prediction

Tests are often used as the basis for predicting what a person might do in new circumstances. For example, will a particular boy be likely to succeed in training as an aircraft pilot? To lessen the chances of his failure is important, because his training would take much time and cost thousands of dollars which could have been invested in a successful candidate. Often secondary school personnel are asked to help predict the successfulness of a student in a particular college, also with a large investment of time, money, and hope. Colleges which have studied their admission procedures find that the best *single* predictor of academic success in college is the academic record of the student in secondary school.

The importance of information for predictive purposes becomes immediately clear when we consider grades and their interpretation. A grade is a distillation of your various evaluation efforts, and grading criteria differ between teachers and schools because different information and different weighting scales are used. But others are going to interpret these grades for different purposes; future employers and collegiate admission officers may expect the grades to have a different meaning from that which you intended.

Suppose that you give Susie a grade of "B" in biology. Your grade may mean that Susie is neat, attentive, and cooperative and has a good memory (scores high on tests of recall information). Others looking at this grade may expect it to mean that Susie has certain developed abilities in science, certain operating skills, and an interest in the area of biology; all of which could be extended through further instruction in school or on the job. While each of us may seem free to base our grades on any pattern of evidence we wish, the results must, insofar as practical, be consistent with those of external interpretators who use them as a basis to predict certain behaviors.

But the predictions are not as reliable as is desirable; any additional information may increase the precision of prediction. Therefore, interviews, recommendations, and special examinations are used.

The College Entrance Examination Board was founded in 1900 when the independent colleges began to enroll appreciable numbers of students from widely scattered schools. No longer was it practical to examine the student in person at the college prior to admission. Some less expensive and quicker technique was needed. Despite whatever instructional standards the colleges might recommend to the schools, instruction would differ between schools. As grades probably had different meanings (as they still do), some common basis on which to appraise applicants was clearly necessary. Therefore, a small group of colleges banded together to form the College Entrance Examination Board (CEEB). Now over 200 colleges are members.[20] Steadily the number of schools represented in a collegiate freshman class has grown. At present,

[20] For a report on the history and activities of this Board, see Claude M. Fuess, *op. cit.*

Beginning in 1951 the Board appointed a series of committees to explore the possibilities of shifting the emphasis of the science examinations toward more general scientific attributes. The initial committee thought that their responsibility might be developed and clarified through a single operation.

> The "operation" agreed upon was the invention of a single test designed (1) to measure the level and scope of the candidate's knowledge and his ability to apply this knowledge to solve problems, and (2) to inquire into the candidate's literacy in science as shown by his ability to analyze scientific literature, to analyze the principles of science, and to use scientific methods.[23]

Out of this initial effort, through a series of committees, grew the Tests of Developed Ability which have been tried experimentally on many secondary school seniors and college freshmen. The results though far from conclusive were so encouraging that similar committees were established in the Humanities and the Social Studies. If colleges wish to put greater emphasis in their admission procedures upon developed abilities, such tests would be of great value.

The argument is simple: we are born with certain latent abilities which only become significant as they are developed. Inasmuch as schooling offers opportunities for these abilities to be developed, the degree to which they have been developed should be indicative of further development in college.

In a nearly final experimental form,[24]

> The science test consists of two parts. The first is a 60-item, multiple-choice "glossary" section requiring 30 minutes and covering understanding of the basic forms and concepts in the six areas of science from which problems were selected—physics, chemistry, biology, meteorology, astronomy, and geology.
>
> The second part is a 70-item, multiple-choice section requiring 90 minutes and covering the ability to apply scientific facts and principles to the understanding of data such as one might encounter in further study of science in college or in life. The answers to the questions require in many cases the application of quantitative thinking, particularly in the understanding of graphs or in reading of tables. The basic steps in scientific thinking are applied in reaching conclusions from descriptions of experiments. The student is required to reason scientifically as he predicts the effect of certain treatment. He is required to apply scientific generalizations to specific situations. In all cases, the student must have some knowledge of basic scientific methods and concepts in order to reach correct answers to the questions. The problems are deceptive in that they often appear to be simply reading problems, but a careful analysis reveals that the passages, which appear simple to one with training in science, seem to have little meaning for one without scientific training. Reports from the experimental administrations indicate that many students who had taken no courses in science were unable to make progress with the questions.

Just what usage will be made of these tests and when is not yet decided. But the indication is clear that the CEEB is desirous of shifting the emphasis of its examinations more toward the direction of developed abilities. The

[23] P. F. Brandwein, "Science Teaching and the Board's Science Tests," *College Board Review*, No. 15, Nov. 1951, p. 227.

[24] Henry S. Dyer and William E. Coffman, "The Tests of Developed Ability," *College Board Review*, No. 31, Winter 1957, p. 9.

TABLE 19-4 *How many students take the CEEB achievement tests in science?*

Subject	*Total enrollment* *	*Exams taken* †	*Fraction of enrollment taking examination*
Biology	1,291,000	7,025	0.0054
Chemistry	483,000	14,933	.031
Physics	303,000	12,396	.041

* K. F. Brown, *Offerings and Enrollments in Science and Mathematics in Public High Schools, 1954-55*, U. S. Government Printing Office, Washington, D. C., 1956. As a description of the population who might have taken the examination, these figures are too low, as they omit about 8 per cent of the age group enrolled in nonpublic schools.

† *Fifty Fourth Annual Report of the Director, 1954*, The College Entrance Examination Board, N. Y., 1956, p. 62. In 1954-55, 71,013 students took a battery of three achievement examinations.

studied by the Board; even though they advised the "cram instructors," little or no significant gain was shown by the "crammed" students.[23]

Ironically, this very intent upon the examinations may so warp the instruction that students who seemingly do well or are known to have "studied" the subject in secondary school are ultimately almost indistinguishable from others in college who have not "elected" the course in secondary school. Since a student takes only three achievement examinations, usually including English, he cannot take examinations in all the subjects studied even in his senior year, let alone through his entire secondary school career. Usually only a small fraction of any particular class of seniors does take the examination in that subject. The 1954-55 figures are shown in Table 19-4.

In the light of this information, we cannot but be deeply concerned about those teachers who insist that their primary responsibility to the pupils enrolled with them is to "prepare them for the college entrance examinations." Our worry about such a narrow view of a teacher's responsibilities is enhanced by observation of the seemingly indefensible "cramming" methods often used. We earnestly suggest that teachers concerned about these examinations examine their school records for the past five years and derive the actual percentage of their class enrollments who have taken these examinations. The results may be thought-provoking.

During the early years of the CEEB, syllabuses were published in each subject to assist teachers in readying students for the examinations. About 1941 the publication of such syllabuses was generally discontinued.[24] Through the 1930's into the 1950's the emphasis in the examinations gradually changed to include emphasis upon application of principles as well as recall.

[23] Henry S. Dyer, "Does Coaching Help?" *College Board Review*, No. 19, Feb. 1953, p. 331. John W. French, "An Answer to Test Coaching," *College Board Review*, No. 27, Fall 1955, p. 5. *Fifty-Fourth Annual Report of the Director, 1955*, CEEB, N. Y., 1956, p. 45.

[24] John T. Tate, "Proposed Revision of the Requirements for the College Entrance Exam in Physics," *Am. J. Phys.*, *8*, 246, 1940; "The Chemistry Examination of the College Entrance Examination Board," *Journal of Chemical Education*, *17*, 413, 1940, and "The Physics Examination of the College Entrance Examination Board," *Am. J. Phys.*, *9*, 304, 1941.

9. *Ability to read scientific materials critically*

   This is designed to include such abilities as the ability to identify the allegedly or pseudo-scientific and to recognize such things as the adequacy of data, accuracy, amount of approximation, use of significant figures, and extrapolation.

10. *Ability to apply scientific laws and principles to familiar or unfamiliar situations*

    Some element of this ability will probably be tested in almost every item that can be devised. However, in a properly designed test, few items would fall *solely* into this category.

Notice the complete lack of any mention of specific subject material. Notice also the similarities of this statement with the general operating skills and abilities listed by Nedelsky and by Burke and those in books on the aims of general education in science. Emphasis upon general objectives such as these is very significant, for these objectives are "subject-matter free"; that is, they appear over and over again in the behaviors of scientists irrespective of the particular subject or problem being studied. Thoughtful examination of the potentialities of almost any scientific problem will reveal that its investigation would require many or possibly all of the abilities listed.

As an example, examine the following test item from a preliminary form of the science examination which shows the intent and form of the new tests.[23]

Sample Test Item

TEST OF DEVELOPED ABILITY IN SCIENCE

In order to breed cows which produce large amounts of milk, one must determine the bull's transmitting ability—his ability to pass on the traits of good milk production. The chart [p. 422] is a method developed by Heizer which he found useful in selecting bulls with high transmitting ability. These bulls were then mated with cows.

This chart is used for determining the transmitting ability of a bull in regard to milk production. The formula is based on measurements of the daughter's milk production.

To use the chart, locate the daughter's average production at the left, follow horizontally to the right until the diagonal line is reached, and then follow vertically down and read the figure on the base line. Subtract from this figure the mother's average production. The result is the bull's transmitting ability.

1-2. Bull A was mated with a cow and over a period of years produced six daughters. The average milk production of the daughters was 15,000 pounds. The average milk production of the mother was 14,000 pounds.

Bull B was mated with a cow and over a period of years produced seven daughters. The average milk production of the daughters was 14,000 pounds. The average milk production of the mother was 16,000 pounds.

1. On the basis of the data, the transmitting ability of Bull B, in pounds is approximately

(A) 14,000 (B) 15,000 (C) 16,000 (D) 17,000 (E) 18,000

2. On the basis of the data, a farmer wishing to buy a bull

(A) should pay a higher price for A than for B

[23] P. F. Brandwein, *The Gifted Student as Future Scientist*, Harcourt, Brace, 1955, pp. 85-87.

particular science abilities which eventually were adopted as the basis for the exploratory Test of Developed Ability in Science appear below.[27]

BASIC INTENTS OF TEST OF DEVELOPED ABILITIES IN SCIENCE

I. Scientific Thinking

1. *Ability to identify and define a scientific problem*
   This category includes the ability to recognize the problem present in a given situation, to isolate the problem from the extraneous material, and to define the problem in specific terms preparatory to devising solutions
2. *Ability to suggest or recognize a scientific hypothesis*
   Within this category fall such abilities as the ability to synthesize data pertinent to a problem and the ability to recognize the possibility of testing an hypothesis.
3. *Ability to propose or select validating procedures (both logical and empirical)*
   This encompasses the design of experiments, the ability to plan or recognize an adequate plan for the collection of data, the ability to make logical predictions, and the ability to design apparatus set-ups.
4. *Ability to obtain requisite data*
   Examples of abilities which would fall within this category are the ability to make observations, the ability to manipulate laboratory equipment, and the ability to assemble laboratory equipment in a logical sequence.
5. *Ability to interpret data, i.e., to recognize or formulate valid conclusions or generalizations from information known or given*
   This encompasses the ability to interpret data given in maps, charts, graphs, diagrams, and verbal materials, and to make generalizations or draw conclusions based on data given. In essence, this is the ability to extract from collected data evidence verifying or disproving a given hypothesis
6. *Ability to check the logical consistency of an hypothesis with relevant laws, facts, observations, or experiments*
   This category includes the ability to recognize the applicability, logical consistency, and plausibility of an hypothesis. In essence, this is a synthesis of abilities 2, 3, and 5.

II. Scientific Skills

7. *Ability to reason quantitatively and symbolically*
   This ability encompasses three major manipulative skills:
   a. ability to understand and perform numerical operations
   b. ability to understand and use symbolic relations
   c. ability to understand and use information presented in graphs, charts, tables, diagrams, maps, and verbal materials
   The abilities included within this category are considered to be purely manipulative, e.g., the ability to read a graph or an equation.
8. *Ability to distinguish*
   a. among fact, hypothesis, and opinions
   b. the relevant from the irrelevant
   This is essentially the ability to abstract the vital information from a wealth of data collected by someone else, and to ignore the information extraneous to the problem at hand.

---

[27] Through the permission of the College Entrance Examination Board.

(A) Both predictions will be equally reliable since both are based on the same principle.
(B) The prediction involving 14,000 pounds will be reliable since it is on the present graph, but the other prediction will be wrong.
(C) The prediction involving 14,000 pounds will be reliable since it is read in a region where the data show that the principle holds, while the other prediction is less reliable because it goes beyond the region where the data are shown to hold.
(D) Both predictions are reliable since a straight line graph can be extended indefinitely.
(E) It is impossible to answer this without knowing more about the breed of cattle.

To help you recognize the knowledge, skills, and abilities required to answer the five items of this question, we suggest that you answer each part and record what you were obliged to recall and to judge as you reached an answer. These five items call upon quite different developed abilities. The amount of recall information is low; most of what is needed is given. Yet the items are not easy.

If examinations based on these general abilities are adopted by the College Board and are also used frequently in secondary schools as well as colleges, we shall have, for the first time in a half century, consistency between the behavioral objectives of science instruction in the secondary schools and in the colleges, as well as in the tests used as screening devices between them.

You may find some of the following references on evaluation useful.

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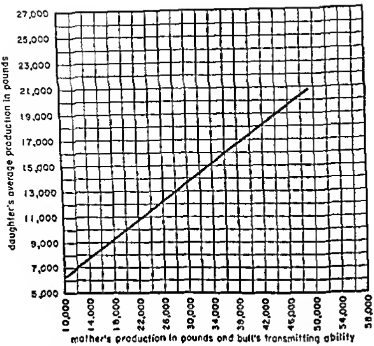


(B) should pay a higher price for B than for A
(C) should pay the same price for both bulls
(D) should buy neither of these bulls
(E) cannot tell which bull is worth more

3. The chart given is in reality
(A) a hypothesis
(B) a generalization based on experience
(C) a result of theoretical study
(D) a law of breeding affecting all animals
(E) none of the above

4. "It can be predicted that a bull with high transmitting ability will have daughters with high milk production." This statement is
(A) warranted by the data in the chart
(B) contradicted by the data in the chart
(C) too difficult to check
(D) only partially correct because it does not contain data on the milk production of the mother
(E) only partially correct because it does not contain data on the breed of the bull

5 The chart is extended in order to make a prediction of the bull's transmitting ability where the daughter's production is 23,000 pounds and the mother's production is 30,000 pounds. Which one of the following is true in regard to this prediction compared with a prediction where the daughter's production is 14,000 pounds?

take or choose to take, such as the special examinations for college entrance, scholarship examinations, etc.

What sort of program would suit their purposes?

The realities of the situation. As throughout the nation, the teachers knew that many of the students (at least 60 per cent in this school) did not have the ability to succeed in college. Of approximately 40 per cent who would apply to college,[1] a fair number would choose to take the College Board Examinations in physics or chemistry, and the fewest in biology (see p. 418).

Nearly all of the students would take the Regents Examinations. (Approximately 90 per cent did.)

Different tracks. Early in its history, this science department had decided to institute different tracks for the science shy and science prone (see Chapters 8 and 9). After some thirteen years of work, the tracks described in Chapter 3 were developed (see Table 3-4). Naturally, different tests needed to be developed for each track. For instance, a course in physics which is highly mathematical in its treatment cannot be evaluated with the same testing tools appropriate for a descriptive course in physical science. A course in advanced science (with its base in project work) has a different basis for evaluation than a course in biology.

Par value. If one develops different tracks for different students, having different interests and abilities, one cannot expect all students to reach the same degree of accomplishment. With any instrument of evaluation, e.g., a paper-and-pencil test, one expects the scores of students to "spread" as a result of their effort. This would be fine, if we began with students of equal promise.

But we are again reminded of Harold Hand's fable (page 146); Sam Sparrow and Sid Swallow will do differently in the same course in flying, not because of effort or interest, but because of different hereditary qualities. It seems reasonable that a sparrow that flies as well as he can, and a swallow that flies as well as *he* can should each be awarded the highest grade for the highest expression of his ability. Thus a sparrow would get an A for flying his best, and so would a swallow.

Put another way, since children do not choose their parents or their heredity, they should not be stigmatized for them. However, the realities of our present way of life cannot be dismissed; there seems to be a need for knowing the accomplishments of people in terms of a "*standard*" which has been established, and which is generally understood.

In this science department, there was an attempt to establish a grade based on the principle of *par value*. Essentially this meant that a student who worked to the best of his ability (par for his ability, par for the course) should get the highest grade. Thus a student with a 90 I.Q., who worked to the best of his ability, would achieve the same grade (100%, or A) that a student with 150 I.Q. would achieve if he worked to the best of his ability. This seemed equitable. Yet surely, colleges and employers would not accept this practice, because to

[1] This is rather high compared to the nation where about 30 per cent of the graduates enter college.

CHAPTER 20

Appraising the student:

An approach to test building and interpretation

A note at the beginning: All teachers make tests. All teachers are constantly faced with the twin tasks of improving their tests and interpreting test scores. While we cannot go deeply into either of these operations, we hope that what we say is sufficient to be of some help, at least, initially; expertness in testing comes after long experience.

We begin with a case study in which a test was designed that actually stimulated students to read and learn more than they would have without the test. Testing is concerned not solely with measurement, but also with stimulating learning. Then, in a lengthy "Excursion," we consider some aspects of test-making, interpretation of standardized test scores, and the meaning of "scaled scores" of various types.

A case study in evaluation

The group of teachers who comprised one science department (an actual one) had the usual run of youngsters, from I.Q. 70-75 to the upper end of the distribution curve. They had to give grades to all. They had to give tests, for many reasons:

1. As a basis for determining the extent of learning.
2. As a basis for determining the success of teaching.
3. As a basis for reporting through grades the success of learning to parents.
4. As a basis for reporting to the administration, for purposes of diagnosis, promotion, and guidance.
5. To comply with the New York State Board of Regents directive: all who finish a unit of work (a year's study) must take a Regents Examination in the area. (Science Regents are given in biology, chemistry, physics, and earth science.)
6. To prepare young people for various examinations they will need to

that more than memorization was needed to achieve a high grade. In addition, practice was given students in taking tests; methods of study were illustrated and discussed; methods of preparing for examinations were analyzed; psychological tricks in doing short answer items and essay tests were developed.

Teacher participation in the program of evaluation. In the department under discussion, the teachers participated in developing tests as fully as they wished. Eventually, it was recognized that tests made by teachers were not necessarily valid or reliable, if only because effective test items are difficult to develop. Finally, it was realized that for testing the recall and application of information, teachers in New York were fortunate, for the Board of Regents had over the years developed a rather full series of examination items in all science areas.[2] These items had been pretested, and there were over 1000 items in each subject area.

The teachers who were interested (and not all were) placed on a card the following information for each item:

Topic *Physics*

Item: To produce an enlarged virtual image with a convex lens, the object distance should be (1) less than 1f (2) between 1f and 2f (3) greater than 2f.

Average per cent giving correct response: 75%

Note that space was left for an indication of the response to the item; this was desirable in view of the use of these cards. Once these responses had been determined by a number of uses of each item, a test could be assembled of 50 such items, of which:

10 were of the type in which about 15 per cent of the students had previously given successful responses.

10 were of the type in which about 95 per cent of the students had previously given successful responses.

30 were of the type in which about 70 per cent of the students had previously given successful responses.

After several years of experience, we were able to build tests which gave the spread of scores we wanted: an average score around 75% to 80%, with ten per cent of the scores above 90% and ten per cent of the scores below 60%.[3] By selecting test items of known difficulty in this way, tests can be built to produce any pattern of scores desired.

Not only short-answer items, but also situational items and essay items were developed (see below). The essay items were specially designed for reliability in rating.

Out of this interest in developing their own testing program, the teachers

[2] These items are useful for testing subject matter knowledge in all schools throughout the nation; in our experience, they are as good as any devised elsewhere.

[3] Parents were glad to know that care was being developed in preparing the tests. Furthermore, they were also impressed by the fact that care had been taken in getting a kind of "norm" so that students were being treated fairly.

them a grade of A has different meaning. The school's report would be inconsistent with the meaning attached to it by others.

To make a long story short, eventually there was established in the school, as in some other school systems, a General Diploma not intended for acceptance for college entrance. The science department could then institute a modification of this principle of par value; that is, students who were not intending to apply for college entrance could be graded on a different base line. In short, a "G" grade was instituted; thus science-shy students could achieve a grade of 90G (and conceivably 100G) in tests (and courses) specially designed for them. These tests consisted of nonmathematical items; certain of these tests involved the use of texts to which the student could refer. The G grade was acceptable toward a General Diploma, but not toward a College Entrance Diploma.

In any event, as unsatisfactory as the situation still is, a student with a low I.Q. would not be failed if he worked to his capacity. Similarly, although he could get a diploma and would thus be graduated, his grades would be differentiated by the symbol "G." This would, in a sense, presuppose that the students' capacities had been tested in classes where so-called "regular" standards obtained, and that these students could not meet these standards. Schools have far to go before creating a report system which meets the goals of sound social and psychological, as well as educational, thinking. But the injustice of "failure" for unequal heredity can be ameliorated with a device such as this.

Student sharing in testing. At the beginning of any course, particularly in general science, the meaning of grades and the nature of testing were discussed with the students. Students more readily accept the distasteful task of taking tests when they have discussed the need for tests, when they have a part in formulating the goals of testing, when they have a part in planning the extent and time of the test. For example, they prepare test questions, and have practice and advice in taking their own tests in preparation for taking a test.

Similarly, as students understand the total scope of the testing program and the way it will be used in developing their grades, they collaborate in the learning and teaching process. In this department of which we speak, the final grade was determined as shown in Table 20-1. It became clear to the students

TABLE 20-1 Determinations of final grades

Type of evaluation	*Per cent of final grade*
Paper and pencil tests	70%
An estimate of laboratory work	10%
An estimate of participation in class (oral reports, written reports, committee work, including a report on a book)	10%
A project (an exhibit, or a piece of apparatus, to illustrate a principle of science, prepared at home)	10%
	100%

13. A ray of light will bend ______ the normal when entering a medium of greater optical density. 13______

21, 22. When viewing red print on a white background through a blue glass filter, the letters will appear (21) ______ while the background will appear (22) ______ 21______ 22______

PART B

5. If a man uses a force of 30 pounds to move a 200 pound safe 10 feet, the work done is ______ foot-pounds. 5______

6. The electrical resistance of a wire is inversely proportional to its ______ 6______

7. A 500-gram weight is approximately equal to a ______-pound weight. 7______

8 Fifty centimeters below the surface of fresh water, the pressure in grams per square centimeter is ______. 8______

9. A change in the emphasized overtones will produce a change in the ______ of a sound. 9______

10 A 2 horsepower motor can do work at the rate of ______ foot-pounds per second. 10______

11. A note three octaves above a note of 100 vibrations per second has ______ vibrations per second. 11______

12 The alternating current in the armature of a generator is converted to direct current by a device called a (an) ______ 12______

13. A 550-watt toaster that draws 5 amperes must have a resistance of ______ ohms. 13______

16. The specific gravity of uranium is 18 7. Ten cubic centimeters of uranium weighs (1) 1.87 grams (2) 8.7 grams (3) 28.7 grams (4) 187 grams. 16______

17. A device used for "atom smashing" is the (1) electron microscope (2) cyclotron (3) oscilloscope (4) electroscope. 17______

18 A wire heated to incandescence emits (1) protons (2) neutrons (3) mesotrons (4) electrons 18______

20 The number of calories of heat liberated when 1 kilogram of water freezes is (1) 80 (2) 540 (3) 80,000 (4) 54,000. 20______

21. The resultant of two forces is a minimum when the angle between the two forces is (1) 0° (2) 45° (3) 90° (4) 180°. 21______

23. When the carbon granules in a telephone transmitter are compressed, the current in the transmitter circuit (1) ceases (2) decreases (3) increases (4) remains the same. 23______

24. The decrease in pressure at the top of a chimney when the wind blows across it is explained by a physical principle first stated by (1) Torricelli (2) Pascal (3) Bernoulli (4) Boyle. 24______

25. An aneroid barometer consists of part of a can containing (1) water (2) mercury (3) a partial vacuum (4) compressed air. 25______

28. An object falls from an airplane. As it approaches the earth, there is an appreciable increase in its (1) mass (2) velocity (3) acceleration (4) potential energy. 28______

33. Momentum is equal to the product of mass and (1) force (2) time (3) velocity (4) acceleration. 33______

34. Of the following, the unit of energy is the (1) ampere (2) watt (3) gram (4) calorie. 34______

37. A bullet fired horizontally at a speed of 2,000 feet per second will (1) fall 32 feet during the first second (2) fall 16 feet during the first second (3) not fall at all (4) fall less than a foot. 37______

in this department developed an exceedingly interesting device: a test that actually stimulated students to study harder.

A test which stimulates students to study harder. As is the custom elsewhere, the teachers in this department were accustomed to testing students at the end of a unit of work. One of the teachers hit on the scheme of not only testing students on the unit which they had completed, but giving them "bonus" questions on the work not yet done in class—a bonus for "knowing more."

Finally, four of the teachers in the department used a test somewhat like the example which follows. Part A is concerned with work just covered. Part B consists of items which span the entire course. Some of these items are based on review, others involve new topics not yet considered in class. The effect of the test was to stimulate the student to review and to read ahead, since at all times he could receive credit for "knowing more." Since in the "bonus" questions we wished to encourage knowing rather than guessing, a penalty for incorrect answers to these questions was applied. Such tests were given throughout the entire year. The procedure was acceptable to students and parents.

What happened when students consistently received scores over 100, as a number of the best did? The parents of these students received letters (duplicates of which were put in the students' cumulative envelopes) indicating that these students were entitled to the department's recommendation. These letters were prized by both parents and students.

Assume that the students have just finished work on lenses and on refraction and diffraction. We reproduce only *sample* items here; the tests generally had at least 25 items in Part A and 50 objective and essay items in Part B.

Directions to the student. Scoring plan for Part A: 4 points per item. Remember, however, our usual practice. You may earn extra points from Part B. For any item taken in Part B we offer 1 credit for a correct answer, but 2 credits will be taken off for an incorrect answer. You may take any part of an essay question for the same credit as any other question.

PART A

1. The image produced by a pinhole camera is inverted because (1) light travels in straight lines (2) there is no lens (3) focusing is impossible. 1____

4. Images formed by plane mirrors are always (1) laterally reversed (2) real (3) smaller than the object. 4____

5. Wall painting is stippled (made rough) in order to avoid (1) diffuse reflection (2) absorption of light (3) regular reflection. 5____

7. Rays of light coming from a point and passing through a convex lens will (1) necessarily emerge parallel to each other (2) converge at the principal focus (3) converge at a point other than the principal focus. 7____

9. The wave length of red light is (1) less than (2) greater than (3) equal to, the wave length of blue light. 9____

10. The speed of red light in glass is (1) greater than (2) less than (3) the same as, the speed of blue light in glass 10____

11. A body that emits its own light is called a ____ body 11____

12. The portion of a shadow that is only partly darkened is called the ____ 12____

c. Steel plates are fastened together with red hot rivets.
d. A large soap bubble is not crushed even though a total force of several hundred pounds is exerted on it by the atmosphere.
e. Although a piece of metal and a piece of wood are both at a temperature of 40° F, the metal feels colder than the wood.
f. An electric refrigerator tends to increase the temperature of the room in which it operates.

8. A 180-ohm resistor, a 60-ohm resistor, and an ammeter are connected in series to a 120-volt source.
a. Draw a labeled diagram of the circuit.
b. What current should the ammeter indicate?
c. Find the voltage drop across the 180-ohm resistor.
d. Find the wattage in the 60-ohm resistor.
e. In which resistor will the heat be developed at the greater rate?

We have sampled here a test in physics; similar ones were given in general science, biology, and chemistry as well.

Most important of all was the fact that students of all calibers liked these tests; the science shy because they had the opportunity to make up deficiencies, the science prone because they were rewarded for knowing more. It was a fact that most students in the class actually finished the textbook before the year was up, and that most students kept up a constant review. If tests have to be given, if subject matter knowledge has to be tested, why not use tests to stimulate additional study?

Incidentally, although a large file of test items was drawn upon so that no two tests were alike, individual items often appeared several times. There was no restriction on a student's selecting again an item he had previously received credit for. The teachers felt that it was just as important for a student to get the right answer a second time as it was the first time. And, of course, knowing that their information was not a dead issue once they had exhibited it, students were more likely to *retain* information.

This department furthermore developed from these tests a criterion of promise in science; undoubtedly there are many others. Gradually we found that students who consistently scored 120 and over on tests such as the preceding were in the group which we described as the science prone. These students worked harder, had higher ability (verbal and mathematical), and were better organized than their age mates.

Standard examinations. A group of conscientious teachers cannot make tests and grading scales without desiring some check on its judgment, its teaching program, its achievement.

This department gave three sets of tests at five-year intervals to a random sample of its students. These tests were:

1. *Tests of Primary Mental Abilities,* published by Science Research Associates, Chicago, Ill. These describe the caliber of the students as a check against the tests already available (I.Q. score, reading score, and arithmetic score).
2. Tests 2 and 6 of the *Iowa Tests of Educational Development:*

39. An increase in the amplitude of a sound wave increases the pitch of the sound. 39.____

40. The strength of an electromagnet depends upon the current and the direction of winding of the coil of wire. 40.____

41. Heat is transmitted from the sun to the earth by conduction. 41.____

44 The volume of a gas at constant temperature varies directly with the pressure. 44.____

45 A lead storage cell was charged. The electrolyte's density increased. 45.____

46 If a low resistance shunt is placed across the terminals of a galvanometer, the instrument may be used as an ammeter. 46.____

50 Light of a single wave length (monochromatic light) cannot be refracted. 50.____

1. Describe simple experimental procedures that may be used to determine *five* of the following:

   a. The dew point of the air in a room
   b. The two fixed points on an unmarked thermometer.
   c. Which of two metals is the better conductor of heat.
   d. The effect of a change of pressure on the boiling point of water.
   e That there is no change in temperature during a change of state.
   f Which of two liquids has the greater heat capacity.

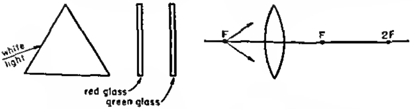
4. a. A boy is given a mallet, a few elastic bands, and two tuning forks of the same frequency, mounted on resonating boxes. Explain how he could demonstrate: (1) Sympathetic vibration (2) Beats.

   b. A hunter fires a gun and hears the echo from a cliff 11.4 seconds later. The temperature is 10° C.
      (1) Calculate the speed of the sound
      (2) Find the distance from the hunter to the cliff.

6. a. Find the candle power of an arc lamp in a motion picture projector that will produce an intensity of illumination of 0 25 foot-candle on a screen 100 feet from the lamp.

   b. A spotlight with a red filter casts a beam of light on a couple on a darkened dance floor. The boy wears a blue suit and the girl wears a red dress. State and explain the appearance of the suit and of the dress when viewed under these conditions.

   c. Copy and complete *each* of the diagrams below to show the paths of the light rays indicated



7. Give an explanation based on physical principles for each of *five* of the following statements

   a. The weight of an object may change although its mass remains the same.
   b. When a thermometer is placed in boiling water, the mercury falls slightly and then rises.

a. *Application of Principles in Science*
b. *Application of Principles in Physical Science*
c. *Application of Principles in Biological Science*

Published by Cooperative Test Service, Revised Series, Form Q, New York:

d. *Cooperative General Science Test* (Form Q)
e. *Cooperative Biology Test*
f. *Cooperative Physics Test*
g. *Cooperative Chemistry Test*

Obtainable from Science Research Associates, Chicago:

h. *Iowa Tests for Educational Development,* particularly, "General Background in the Natural Sciences"; also "Reading–Natural Sciences."

Obtainable from the World Book Company, New York:

i. *Read General Science Test*
j. *Nelson Biology Test*
k. *Anderson Chemistry Test*
l. *Dunning Physics Test*

m. In addition, Dr. Dressel and Dr. Nelson have developed a comprehensive folio of college test items obtainable through Educational Testing Service. It may suggest test items appropriate to your classes.

n. Practically every large publisher of textbooks offers accompanying booklets of tests. There are a multitude of items in each test.

3. There are also useful general guides to test construction. We list a few of them:

Fourth Mental Measurement Yearbook, ed. by O. K. Buros, Highland Park, N. J.: Gryphon Press, 1953. (This is one of a group of test reviews.)
Gerberich, Joseph R., *Specimen Objective Test Items,* N. Y.: Longmans, Green, 1956.
Graves, R. M., *How to Make Achievement Tests,* N. Y.: Odyssey Press, 1950.
Hawke, H. E., E. F. Lindquist, and C. R. Mann, *The Construction and Use of Achievement Examinations,* Boston: Houghton Mifflin, 1936. (Although "old," still very useful)
Micheels, W. J., and M. R. Karnes, *Measuring Educational Achievement,* N. Y.: McGraw-Hill, 1950.
Raths, L. E., "Techniques for Test Construction," *Educational Research Bulletin,* Ohio State University, 17:85-114, April 1938.
Thomas, R. Murray, *Judging Student Progress,* N. Y.: Longmans, Green, 1954.

4. In addition, there is clearly another most important source of test items. This source is at the cutting edge of research and test development. For instance, there is the "Thinking Project" of the University of Illinois. Its aim is to study the way young people think; but, as a result of the work, a multitude of interesting test items were developed (much as in the Eight-Year Study). Two of the items are offered here, as examples.

Test 2 (Form Y-2), "General Background in the Natural Sciences."
Test 6 (Form Y-2), "Interpretation—Natural Sciences."

3. Regular examinations of the Board of Regents in biology, chemistry, and physics, through which comparisons were made with the achievements of similar schools in the state.

The net result of this plan of evaluation we have described was to feed back to the members of the department information on the effectiveness of their teaching. This led to constant review of their purposes and goals. And this is a major purpose of evaluation: the improvement of instruction.

An excursion into developing one's own evaluation program

Sources of test items and information

Teachers, as we have found in years of teaching, have too little time—especially to build good test items again and again. Hence, the need for building a file of test items. After a few years the items will accumulate, and under repeated use with different classes, they will be appraised for their reliability and validity. Continued additions refresh the file. Of course, security must be maintained, a locked file, for instance, is invaluable.

One teacher built up a fairly useful file (over a period of five years) somewhat as follows:

1. *A file of short answer items.* He obtained files of examinations (of items which were permitted to be duplicated) from the Chicago Examiner's Office and from the New York State Board of Regents. These items were in general science, biology, chemistry, physics, and earth science. These were of the type detailed on p. 428. In this way, he collected some 500 items in each area, each one on its own card. He could assemble an examination of any type within a short time. Also, he kept discarding items which proved unsatisfactory.

2. *A file of essay items.* The state examinations mentioned above (only as examples) also had essay items. These were placed on cards as well. There are many other sources of test items:

1. Pool the items of your colleagues with your own, and thus develop a very rich departmental pool of items.

2. Study standard tests such as the following for *types* of items developed. These tests will furnish clues for errors and strengths in the items developed by you and your colleagues. (Do *not* copy these test items; they are copyrighted. If you did use those particular items, their patent test would be less significant if given later.)

Published by the American Education Fellowship, formerly Progressive Education Association, New York:

____(4) When the effort moves twice as far as the resistance, the mechanical advantage is two.

e. How did you know which reason in Question d. to check? ....
....
....

From these examples it seems that it is useful to follow the work of groups interested in test development. Do you receive the publications or the announcements of:

Educational Testing Service, 20 Nassau St., Princeton, N. J.
Psychological Corporation, 522 Fifth Ave., New York 36, N. Y.
Science Research Associates, 57 West Grand Ave., Chicago, Ill.
The Science Teacher, 1201 16th St., N.W., Washington 6, D. C.
World Book Co., 313 Park Hill Ave., Yonkers, N. Y.

Notes and hints for the improvement of tests

In Chapter 19 and the preceding pages, we have considered and illustrated many types of test items and the general approach to an effective testing program as part of over-all evaluation. The literature on testing is large and worthy of study; here at best we can add only a few notes and hints that may be helpful to you.

By now you are surely aware that *no test is perfect*. Inevitably the validity of a test is under suspicion. Checks on validity come from comparison with other types of information, especially the observations made day-to-day by the teacher. If the "best" students in a class do poorly on a test, perhaps the test needs thoughtful consideration. Furthermore, you feel more confident about a particular test when you have examined the items in it for their appropriateness to your intentions and to the material considered in class, and its representativeness as a sample of both these attributes.

Preplanning. The prerequisite to a well-planned testing program is a well-planned course or curriculum. As we have indicated earlier, even during course planning specific opportunities will come to mind for appraising the behaviors to be developed. Record these for future use. During the day-to-day operation of the course, interesting possibilities for test items will appear from the discussion and behavior of the students. Note these briefly, but specifically, and file them against the day when a test is to be made. Out of such actions will come more and better materials for your tests.

Blueprinting a test is highly recommended by many experts. They propose a two-dimensional layout of behaviors to be tested and materials to be used. Such a pattern would look like Table 20-2. This pattern of item distribution is entirely hypothetical, but it illustrates how the various subject areas and the pupil behaviors can be weighted in the test. In addition, attention would necessarily be given to the distribution of the difficulty of the items so that these

In chemistry

CAN YOU TELL WHETHER OR NOT A CONCLUSION IS REASONABLE?

Surrounding the nucleus of the uncharged lithium atom, there must be three electrons, since the number of electrons and the number of protons in any uncharged atom are the same.

a. State the conclusion of this reasoning. ....

....

....

b. State the reason given for the conclusion. ....

....

....

c. How did you know that the statement you wrote in Question b was the reason and not the conclusion? ....

....

....

d. The second reason for the conclusion was not stated. It is assumed. Check the one of the following statements which is the assumption.

——(1) There are three protons in the uncharged lithium atom.
——(2) Electrons revolve around the nucleus of an atom. The nucleus contains the protons.
——(3) Each electron being negative cancels a proton which is positive.
——(4) An atom is thought to resemble a solar system with the protons in the position of the sun and the electrons like the planets.

e. How did you know which reason in Question d to check? ....

....

....

In physics

CAN YOU ANALYZE A BIT OF REASONING?

A pulley can be regarded as a lever. When the resistance is attached to a movable pulley, the lever arm of the resistance is the radius of the pulley, and the lever arm of the effort is the diameter of the pulley. Since the diameter is twice the radius, the mechanical advantage of a single movable pulley is two.

a. What is the conclusion of this reasoning? ....

....

....

b. What are the reasons given for this conclusion? ....

....

....

c. How did you know what was the conclusion and what were the reasons? ...

....

....

d. Another necessary reason for the conclusion is not stated. It is assumed. Check the one of the following statements you believe is the assumed reason.

——(1) The mechanical advantage of a machine is the ratio of the resistance to the effort.
——(2) When the effort arm of a lever is twice the resistance arm, the mechanical advantage is two.
——(3) The resistance attached to a single movable pulley is supported by two strands.

should be tailored to the time available so that all, or nearly all, students complete all items; only for particular types of skills like reading comprehension or computational speed is a "speed test" defensible.

To expedite test scoring, prepare in advance a scoring key. This may also assist you in recognizing any questions that have ambiguous answers and in modifying them before the pupils take the test. Often such a scoring key will be a strip to be aligned with the answers. This is readily done if all the answers are placed along one margin of the test sheets.

Have the tests duplicated and legible. There is no excuse for the slow process of reading questions to pupils who may not hear the words correctly or may still be thinking about the previous question. Reading questions aloud slows down all students and severely limits the number of items that can be used in the time available. Likewise, writing test items on the board, even essay questions, is undesirable; many times the students may mistake the writing, unless it is very clear. Provide each child with an explicit written statement of the task. But above all, make certain it can be read; a test is not supposed to be a guessing game. This may sound unnecessary to say, but we have seen the unreadable tests given students in some schools we have visited.

Make certain that the correct answers are randomly distributed. Flipping a coin will provide a random basis for the arrangement of true-false items. Rolling a die will provide a means of randomizing the correct answer's position in multiple-choice items.

Arrange with the school office that no unforeseen events will interrupt your test period. announcements, shortened periods, or cancelled sessions. The children will have done some preparation or at least will be expecting the test as scheduled. Delays are confusing and irritating to them.

Pupil scoring. Pupil scoring can expedite the results of a test. But if this is done, you are advised to assign each pupil privately a number in some random manner. This number and *not his* name goes on his paper. Then, mix up the papers before redistributing for scoring. Provide each student with a written scoring key. Have him indicate in a box on the test the number of right, wrong, and omitted answers. For safety, have another pupil rescore each paper. Results can be posted on the bulletin board by each student's number. Some interpretation of the over-all distribution of test scores should also be posted. This may be in terms of rank-in-class or letter grades with the cutting scores identified.

Choice of items. Any test is a sample of student behavior. Therefore, the difference between a good and a bad test lies in the sampling procedures used. A good test meets five main criteria:

1. A good test is *long enough* to provide a stable, or fair, sample of the student's behavior. To base any conclusion on only a few items is to have an unreliable conclusion.

2. A good test contains a *representative sample* of items. The items should be chosen on three bases: difficulty, subject content, and behavior required.

TABLE 20-2 **Distribution of items in hypothetical blueprint for a test of developed ability in science**

		Subject area				
		Biology	*Chemistry*	*Physics*	*Earth science*	*Total*
Behavior	*Demonstrate understanding of principles*	5	5	5	5	20
	Apply principles	5	5	5	5	20
	Handle quantitative relationships	3	5	5	2	15
	Interpret cause and effect relationships	4	4	4	4	16
	Interpret experimental data	5	4	4	2	15
	Apply laboratory procedures	4	4	4	2	14
	Total	26	27	27	20	100

were fairly scattered among the areas and abilities. The totals give the relative weights assigned to the subject areas and abilities. The advantage of such a blueprint in advance of test formation is the prevention of overloading one subject or ability and slighting the others.

The same type of breakdown can be used within a particular subject area, e.g., in biology: botany, zoology, ecology, human physiology or health, conservation. The pattern of item forms may also be laid out and the point scores for each section planned: so many true-false, completion, matching, multiple-choice items and the amount of score attainable from each.

Mechanical details. Specific written instructions for the presentation of the test are recommended. While this may seem unnecessary, an occasion may arise where you might be ill and might have someone else give the test. Also, for comparison with the tests of other teachers, such detail is desirable. Indicate clearly the length of time to be used for the test. Generally the test

This is just a bit too vague! To write better completion items, check carefully on irrelevant clues which may indicate or demand the answer logically or grammatically. Also, be sure to have all blank spaces of the same length.

MULTIPLE-CHOICE ITEMS. These provide opportunity to force nicer distinctions. What you would wish is a choice among a very large number of possibilities, but this is impractical in terms of test length and reading time. *Four or five alternate answers is usually a fair compromise which reduces to* a small factor the likelihood of successful guessing. With four choices, guessing should net a score of only 25 per cent, and leave a significant range of scores from 25 to 100. With five choices, guessing should net only 20 per cent, and leave a significant range of scores from 20 to 100. Either alternate is superior to true-false questions which have a significant score range of only 50 to 100. Correction for guessing can be made if desired.

Some of the more obvious troubles with multiple-choice questions can be overcome by noting the following suggestions.

1. Be alert to irrelevant clues such as frequently putting the correct response in the first or last position; having grammatical inconsistency between the statement, or stem, and certain answers; having similar or related words in the statement and among the answers; making the correct answer consistently longer or shorter than the others.

2. *Insofar as practical, use the direct statement form in preference to an* incomplete statement. Such items are easier to write and will have fewer grammatical inconsistencies. In some instances, the incomplete statement is a natural choice, but use it rarely.

3. Do not use unrelated alternatives as fillers among the incorrect answers. As we indicated above, all alternatives should be plausible enough to catch a few students. If necessary, make up reasonable terms like "chemoglobin" and "hemophyll" that might be confused with "hemoglobin" or "chlorophyll." If only one or two plausible distracters can be found, use only these; or cast the item into a true-false, completion, or matching form.

4. If you use the alternatives "none of these" or "all of these," they should be the correct response in a fair number of cases. These should not be used merely as fillers.

Commonly we ask students to select or provide the correct answer from among others that are incorrect. An inversion of this operation requires the selection of the alternate that does *not* belong to the same group as the others. Recasting an item into this "not agreeing" form will almost always increase its difficulty. If such items are used, be certain that the instructions about the *item, or group of items, of this type are clear. If you plan to use such items,* and they can be very useful, some practice with them in class would be desirable.

MATCHING ITEMS. These should present two lists of unequal length; otherwise by elimination the last pair is a free gift to the student. Keep the lists short, say, 5 to 7 items, to reduce searching time required by students.

3. A good test contains *no ambiguous items.* Ambiguity can arise in two ways. First, the question may be stated in such a manner that the student does not know what is wanted. If he does not understand the meaning of the question, we never know whether he could have answered it or not. Second, the question may be stated in such a manner that it does not involve the behaviors desired We then have an answer, but it doesn't mean what it was intended to mean.

4. A good test contains *no interdependent items.* The answer to question 2 should not demand a correct answer to item 1. If the items are interdependent, then we have fewer honest samples of the student's abilities than we have items. In addition, students should not be able to answer correctly a question whose answer they do not know because they have had clues from responding to a question they do know. This situation arises frequently on tests containing both multiple-choice and matching items, but it can be avoided.

5. A good test contains only items that discriminate between able and less able students. A discriminating item is answered correctly by more of the students who get high general scores than by those who generally do poorly. We discuss discrimination in more detail in this chapter in the section, "Item Analysis."

Comments on various types of objective items

TRICK ITEMS. Test-makers and test-takers have no sympathy for the "trick" question which involves a double negative, a minor change in date (B C for A.D.), wrong units, and the like. They can hardly be claimed as testing the major concepts and knowledge of concern in the course.

SIMPLE QUESTIONS. Simple recall items are basically of the: who, when, where, what type. Often they include what are essentially definitions. These are items that can be answered concisely.

TRUE-FALSE ITEMS. These are difficult to write without many qualifiers which often "give away" the answer. Common difficulties in such questions are these (and don't think that students don't know about them!):

1. Long statements are usually true.
2. Qualified statements, "may, often, sometimes," are usually true.
3. Statements of classification are usually true.
4. Statements of cause or reason are usually false. (They are difficult to write as true statements without many qualifiers.)
5. Very positive statements, "always, never, must," are usually false.

With care, many of these common troubles can be overcome.

COMPLETION ITEMS. These often become a guessing game. Too often they require a recall of a specific statement from a text or a particular word pattern used in class. When many blanks are included in a single item, the question looks like this:

In ____, ____ did ____ to ____.

discriminating power. We must assume that the test as a whole is appropriate (valid). Then we ask to what degree each item in the test contributes to the total scores obtained. The simple procedure for this is:

1. Rank all papers from highest score to lowest score.

2. Separate out the lowest quarter and the highest quarter of the papers. Use only these two sets of papers.

3. For each item record the number of correct answers in each quarter.

4. The sum of the counts of correct responses divided by the number of papers counted provides an *index of difficulty* for each item. An "easy" item will be answered correctly by 75 per cent or more of the students. An "average" question will be answered correctly by about 25 to 75 per cent. A "difficult" item will be answered correctly by less than 25 per cent. This index of difficulty can be recorded on the file card carrying the item. Later it will be useful to know this when you wish to make up another test.

5. Comparison of the numbers of students in the "top" to those in the "lowest" quarter who answered an item correctly shows its *discriminating power,* i.e., whether it is helping separate the high-scorers from the low-scorers. While we assume that each item will do this, sometimes items do not discriminate at all, or they work in reverse. Such items should not be reused until they have been modified. If 100 per cent of the "top" students and 75 per cent of the "lowest" students get an item correct, it is a good discriminator, but an easy question. Similarly, if 40 per cent of the "top" students answer correctly and only 5 per cent of the "lowest" group do likewise, it is a reasonably discriminating item, but a difficult one. A simple record such as 100/75 or 40/05 on the item card in the test file will indicate this information for future use.

Often we wonder what makes a certain question effective or ineffective. When the papers of the top and bottom quarters of the class have been separated, record the number in each group who chose each of the alternate answers. Record also the number who omitted an answer. Now you can see which of the "distracters" or incorrect answers is attracting responses. This may be a clue by which your instruction can be modified. If some of the distracters of a question are attracting no marks, they might be changed to make them seem more likely as answers. Consider these examples:

1. Inorganic salts may be formed by the interaction of (1) a metal and an acid (2) a chloride and an acid (3) glycerine and a fatty acid (4) a metal and a base.

Responses	*(1)*	*(2)*	*(3)*	*(4)*
Upper quarter	16	0	19	3
Lower quarter	21	1	7	5

This item discriminates *against* the upper quarter of the students on the test as a whole. Answer 3 seems to be the overly effective distracter. A worthless question as it stands.

2. The thermometer (1) probably was first devised by Centigrade early in the 16th century (2) actually is never anything more than a constant volume

GENERAL. Two final suggestions may be helpful. Try each item on someone not familiar with the course; a wife or friend does well. If they can see what the question demands, but cannot answer it without the experience of the course, the question is probably clear and valid. Also try questions out casually in class, noting the responses; some of them will provide effective alternate answers.

Test interpretation

Guessing. Guessing on any objective test will always occur. But authorities differ in their recommendations about correcting for guessing, while some teachers feel that one should not correct for guessing at all. If you have a true-false test, half the items would be marked correctly just through guessing. That is, your useful range of scores is only from 50 to 100. If all students mark all items, correction for guessing will not change their rank order; the highest will still be highest, and the lowest still lowest. The same is true of multiple-choice items, but often not all students attempt all items. Then a correction for guessing may be desirable. This is readily done through the relation:

$$\text{Score} = \text{right} - \left[\frac{\text{wrong}}{\text{alternates} - 1}\right]$$

Whether or not this correction is worth the trouble depends in part upon the number of omissions in the test responses and upon your interpretation of the scores. If you are interested in each student's relative place within the group, the correction will make little or no difference in his rank position. The number of omissions indicates whether a change of item might be desirable. Generally speaking, however, students do not "omit" responses; they prefer to guess, or at least they intend to respond "correctly."

Determining the difficulty of a test. To provide you with some indication of the relative difficulty of the test for a particular class or group of classes, derive the median score. This is the "middle" score in the distribution, i.e., the 50th among 99. Also the arithmetic mean score (class average) will probably be useful. These can be posted to aid the students in interpreting where they stood among their classmates.

Two techniques will provide information which allows you to improve your tests: a *reliability check* and *item analysis*. When important decisions are to be made on the basis of a test, we wish to be sure that the test is reliable, that is, measures rather reliably whatever it does measure. Such a coefficient is usually found through the "split halves" technique. This is described in most texts on educational measurements. For well standardized tests, such a coefficient will generally be around 0.95 or higher.

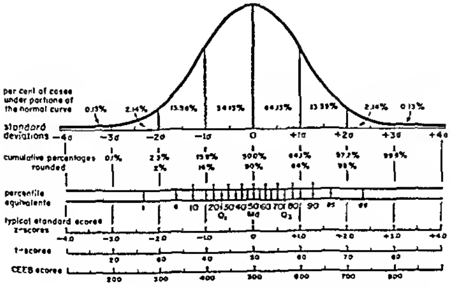
Item analysis. Item analysis can be a complicated operation, and it is when used to study a standardized test under development.

However, there are approximate techniques which can quickly provide you with two useful results. These describe the *difficulty* of each item and its

You can see immediately that we are not likely to get exactly a normal distribution unless we have a very large number of observations. However, most measurements will be distributed in a way close to a normal pattern. For the moment, let us assume that a plot of the scores you have are distributed in a manner close to this normal pattern.

Such a distribution is evenly balanced around a "most popular" value; that is, the distribution is symmetrical. The middle score is also at the balance point, which is another way of saying that the median is equal to the arithmetical mean.

What we want to know is the significance of each separate score within the total aggregate. What meaning can we assign to Henry's 84 and to William's 47? Somehow we need to describe the scatter of the values around the mean. Several different quantities may be used to describe the scatter, but the "standard deviation" is the most popular and most significant. This standard deviation (*defined more fully in the example which follows*) describes the width of the distribution; because it is used so often, it is represented by a symbol, small Greek sigma, σ, or sometimes abbreviated as s.d. As you can see from the drawing below, lines cutting the distribution at steps of 1σ, 2σ, 3σ, etc., cut out different areas under the curve, or different numbers of scores. Between -1σ and the mean (marked 0), there is 34 per cent of all scores, and the same is true between the mean and $+1\sigma$. You can see why we can say that approximately $\frac{2}{3}$ of the scores occur between the limits -1σ and $+1\sigma$. A shade less than 14 per cent of the scores will lie in the zone between 1σ and 2σ from the mean on either side. Even larger differences from the mean are



thermobaroscope (3) is an instrument that gives a direct reading of the quantity of heat in any object (4) is an essential instrument in carrying out the calorimetric method of constant heat supply.

Responses	*(1)*	*(2)*	*(3)*	*(4)*
Upper quarter	1	3	0	32
Lower quarter	0	22	9	5

A highly discriminating item favoring those with high scores on the total test.

A brief look at the interpretation of test scores

Because teachers, especially science teachers, are often involved in the interpretation of test scores of various types, we include this brief look at the meaning of scores and the interpretation of the results of standardized tests.

When you have given a test and scored it, you have a number on each test. This number has meaning, as you expected; otherwise you would not have bothered to give the test. But what and how much meaning it has depends upon what you do with the scores.

The simplest operation is to *rank* the tests from high score to low score. This gives the order in which the pupils achieved. But this information may not be enough.

You will have noticed, however, if you have a goodly number of papers before you, that a few have very high scores, a few have very low scores, and the rest are scattered around some middle score. That is, there is some *central tendency* of the scores. Some measure or description of this center is useful for comparing this group of papers with other groups. Two types of descriptions are most commonly used. One is the *median*, which is the score of the middle paper when papers are ranked from high to low. If there are 101 papers, the median is the score of the 51st paper in rank. Another, often more useful, description of this center is the arithmetic *mean*. It is obtained by adding together all the scores and dividing the sum by the number of scores.

Even more useful information can be obtained from the set of scores, if we make one assumption: that the scores are distributed in a particular pattern known as the *normal distribution*. This distribution pattern occurs in many types of measurements. If we carefully measure lengths or weights many times, we find that we do not get the same result each time. A few observations will differ considerably on the high side; others will differ on the low side; but most will be clustered around some central value. Likewise, if we measure the heights of men being inducted into the Army, we find some very tall, some very short, but most about "average." A graph of the frequencies of these observations has a bell shape called the "normal curve," sometimes known as the "error curve" or the "Gaussian distribution."

The advantages of finding observations that fit this distribution are great, because many mathematical operations can be carried out on "normal distributions" which are described by a particular type of equation.

test is not valid for your use, and you should not compare your students to the group which was used in the standardization. As we noted earlier, students are being taught more science now than in former years, so their knowledge may be greater than that of those used some years ago to establish a "norm." If this is the case, more than half the teachers using the test will find that their class averages above the norm. While this might make each of us feel happy, it would not be an honest comparison.

If the test is one which would be appropriate for children in several different grades, as for example the STEP (Sequential Tests of Educational Progress) series in science,[4] we would not expect children in grade 10 to score as highly as those in grade 12. Then separate means and standard deviations are derived by the test-maker for each grade. The teacher is provided with a table or chart by which each of the original, or "raw," scores can be interpreted in terms of its position among those of the standardizing group.

Another way of handling such a test is to interpret the raw scores in terms of a scale of mean scores that rise with the grade. Thus, in Chapter 9 the arithmetic and reading test scores of certain children in the ninth grade were recorded as equal to the mean of the typical student in the twelfth grade, or as "12.0 in the ninth grade."

A note of caution. The normal curve and the mathematical operations applicable to it can be applied only to scores which are not limited by a set top score, e.g., 100% on a test. In other words, the test must be sufficiently difficult, so that practically no one gets all the items correct; but all should get some items right (none score zero). Such a test cannot have an arbitrary "passing score" unless the test items are carefully tailored in difficulty to permit the test-maker to assert that a desired percentage of the population will score higher. As examples of these different approaches, compare the College Entrance Examinations, reported on a scale from 200 to 800 for interpretations by the colleges, with the New York State Regents Examinations, on which a score of 65% or higher is a "pass" and lower is a "fail." In the latter type of test the majority of scores are crowded within the range 65 to 100, with quite a few probably actually at 100% and the mean score probably near 80%. Such a test does not distinguish well among the more able students, but seems intended only to identify the less able. What level of difficulty and distribution of scores will be used in a test depends greatly upon the use to which the results are to be put.

An example. While standardized tests, by their very name, have scales and tables for the interpretation of each student's raw scores, sometimes teachers wish to derive the mean and standard deviation of a test they have given. We therefore present an example of how such numbers are obtained.

A test has been given to 60 students. The raw scores range from a low of 51 to a high of 93. While we could work with the individual raw scores (as described above), we can make life much easier and introduce very little

[4] Educational Testing Service, Princeton, N. J.

less likely, and only one score in 700 will differ from the mean, on the high side or the low side, by more than 3σ.

If we start with the low end of the distribution and add up the percentages of scores with values less than each σ mark, we find:

Scores less than	-3σ	-2σ	-1σ	Mean	$+1\sigma$	$+2\sigma$	$+3\sigma$
Total percentage	0.1	2	16	50	84	98	99.9

When we use a scale based on standard deviations, we can obtain not only the rank of a particular score among the total group, but also the percentage of students who scored lower.

Sometimes, because a little arithmetic is needed to obtain the numerical value of the standard deviation (see, "An example," which follows), teachers fail to appreciate the information they would have if they did interpret scores in terms of standard deviations. Notice that different tests will have different mean scores because some tests are more difficult than others. Each test is also likely to have a different standard deviation for a representative group of students. How can Johnny's score on one test be compared with Tom's on another test? If we use standard deviations, we might find that Johnny scored higher than 98 per cent of a large group of students, while Tom scored higher than only 16 per cent. In this way scores based on standard deviations can be intercompared. We might also say that Johnny scored at $+2\sigma$ and Tom at -1σ. Such scores are often called "standard scores," or, for short, *z*-scores.

Standard scores have one disadvantage: they involve both plus scores (above the mean) and minus scores (below the mean). To avoid this, another type of score is sometimes used, the "*t* score." As you can see from the illustration, the mean score on this scale is taken as 50 and the standard deviation as 10 points. Then a standard score of -3σ becomes 20 (i.e., $50 - 3 \times 10$) on the *t* scale, while one of $+2\sigma$ becomes 70 (i.e., $50 + 2 \times 10$).

The scores reported on the Graduate Record Examination and those on the College Entrance Board Examinations are *t* scores multiplied by 10, so that the mean is 500 and the standard deviation is 100. You can see why the College Board does not report scores below 200 or above 800: the number of individuals scoring above or below the 200-800 range is exceedingly small, and scores of 200 or 800 tell us that the person did, respectively, very poorly or exceedingly well on the test. If a pupil scored 550 on the Scholastic Aptitude Test, it means that he is $\frac{1}{2}\sigma$ above the mean of the group, or that he scored higher than 69 per cent of those who took the examination. If, however, his score was 450, or $\frac{1}{2}\sigma$ below the mean, he scored higher than only 31 per cent of those taking the test.

Test "norms." To enable a teacher to compare his group of students with a large population of other students in other schools, most standardized tests have published "norms." These are simply a description of the mean score and the distribution around the mean for a large group of scores. To have significance to a particular teacher, the comparison group must have been large, well distributed geographically, and comparable to his students. Of course, if your course stresses aspects quite different from those in the test, the

TABLE 20-3 Calculating the standard deviation

Column 1 SCORE INTERVAL	Column 2 MIDDLE SCORE, S	Column 3 FREQUENCY, f	Column 4 $S \cdot f$	Column 5 ΔS	Column 6 $(\Delta S)^2$	Column 7 $f(\Delta S)^2$
90-94	92	3	276	20	400	1200
85-89	87	4	348	15	225	900
80 84	82	6	492	10	100	600
75-79	77	8	616	5	25	200
70-74	72	15	1080	0	0	0
65-69	67	10	670	5	25	250
60-64	62	7	434	10	100	700
55-59	57	4	228	15	225	900
50 54	52	3	156	20	400	1200
Total		60	4300			5950

$$\text{Mean} = \frac{\text{sum}\,(S \cdot f)}{\text{sum}\,f} = \frac{4300}{60} = 71.6 \cong 72 \qquad \sigma = \sqrt{\frac{\text{sum}\,f(\Delta S)^2}{\text{sum}\,f}} = \sqrt{\frac{5950}{60}} = \sqrt{99.2} \cong = 10$$

for a test, we suggest that you do; then you will have a better understanding of what is meant by the scores reported or obtained from a standardized test.

Certainly there are many operations and niceties of statistical investigation which we have avoided. If you are interested in exploring into further possibilities like correlations between tests, derivation of reliability coefficients, tests of the significance of the differences between tests, we encourage you to consult one or more books like those listed at the end of Chapter 19.

error, if we group the scores within small intervals. Let us take score intervals of 5 points to create 9 or 10 score groups. By a simple tally-count we find the indicated frequency distribution of the scores. For ease in computation we also find the middle score in each score interval, and treat all scores in each group as though they had this middle score; i.e., 72 represents the group scoring between 70 and 74.

By definition the mean score is simply the total of all scores divided by the number of scores. For each score interval we multiply each middle score, S, by the number of scores in that interval, f, and add all these together. Then divide this total score by the number of scores, 60, and we have the mean score. For our example, these arithmetical operations can be done mentally or with scratch paper. If large numbers are involved, a desk computer or an adding machine may be helpful. The mean score comes out as 71.6 (see Table 20-3). This is so close to 72 that we can use 72 as the mean without serious error.

To find the standard deviation, we proceed as follows (see Table 20-3):

1. Find the difference (deviation) between each score (Column 2) and the mean (previously calculated). This difference, called ΔS, is given in Column 5.
2. Square each ΔS value; $(\Delta S)^2$ values are given in Column 6.
3. Multiply each $(\Delta S)^2$ value by the number of times that score appeared, f (Column 3). Values for $f(\Delta S)^2$ are given in Column 7.
4. Add up the column of $f(\Delta S)^2$ values.
5. Divide this sum by the total number of scores (total of Column 3).
6. Take the square root of this number. This is the standard deviation The standard deviation in our example comes out (not entirely by accident) as ten points.

The standard deviation can be defined operationally as the square root of the average of the weighted sum of the squares of the deviations. The rationale of this process can be found in texts in statistics (see the end of Chapter 19); we have presented just the bare bones.

Although the original distribution of scores in Table 20-3 was not exactly a normal distribution, it was fairly near, with a maximum number of scores in the middle of the range and about equally balanced wings on the high and low ends. We would expect ⅔ of the scores to lie in the range 72 ± 10, or between 82 and 62. We do find that 39 or 40 scores out of 60 are within this range. Also we find only one score of the 60 at or above $72 + 2 \cdot 10 = 92$. There are, however, 2 scores at 51, which is just over 2σ below the mean.

If we wanted to, we could change each score into a "standard score," z, by subtracting 72 from it and dividing by 10. These z-scores could be turned into t scores by the relation: t score $= 50 + z \cdot \sigma$, or in this case: $t = 50 + z \cdot 10$. The relationships among these various scores are shown in the illustration.

Not many teachers are likely to perform even these operations for a test they give only once. But if the same test is given in various years, or to several classes, or to classes of different teachers, or to classes in different schools, some basis of comparison is useful. If you have never worked out such scaled scores

The need for scientists

For our lifetime and thereafter, we shall need scientists. We shall also need those who are not to become experts in science but upon whom our scientists depend for sustenance and collaboration. Yes, collaboration, because scientists are not islands; they work in a society which must nurture them, understand them, sustain them, and bring their basic researches to fruition. This is true, too, with artists.

Considerable attention is being given to the process by which a child develops a career pattern which takes him into science or science teaching. While much remains to be learned about this process, at least some characteristics are clear.

1. Practically all young children are curious about the world around them. If this general curiosity is developed into an interest, they may consider a career in science. The development of such an interest stems from opportunities for satisfying personal activity.

2. In the early adolescent years, grades 6 to 9, many children will exhibit or express interest in a possible career in science or technology. Rarely is this a stable commitment, but the experiences they have during these years may continue and solidify their interest, or may turn them away from elective science courses to come later. For this reason, the approach to science in these grades is critical—even more critical than the particular materials considered.

3. After the elective courses in high school are reached, relatively few students will enter the pool of potential scientists. The nature of the school program and the desirability of a sequential program in mathematics operate against picking up many who were previously uninterested in science. Therefore, the maximum number must be kept willing to consider the possibility of a career in science. Once they count themselves out of science, there is little hope of recapturing their interest. Too many other areas of study and work are competing for their attention and successful accomplishment.

4. Many of those in the potential scientist pool will, during high school, shift to other interests as they see varied opportunities for careers in the adult world. Thus, the number in this pool will continue to shrink.

5. As we indicated in Chapter 9, The Science Prone, many, but not all, of the potential scientists will be among the academically most able in the school. High I.Q. score will mark those who *may* continue on as research scientists, but many others of lesser ability can find a niche somewhere in the field of science.

6. Among even the most able, high I.Q. score and interest are not sufficient predictors. Many emotional and home factors influence the child. Of 306 children who chose (it was entirely voluntary) the advanced science program at Forest Hills High School, including 4 years of mathematics and additional laboratory work on individual projects, only about half have continued toward careers in science (research, medicine, engineering).

7. In college only about half those who enter intending to major in science

CHAPTER 21

Appraising the teacher's role:

Supply and demand in science

A note at the beginning: We begin with two pictures of the nature of the scientist and, by direct implication, of science teaching: one negative, one positive. Both are composites, and both are by students.[1]

THE NEGATIVE: The scientist *neglects his family—pays no attention to his wife, never plays with his children. He has no social life, no other intellectual interest, no hobbies or relaxations. He bores his wife, his children and their friends—for he has no friends of his own or knows only other scientists—with incessant talk that no one can understand;* or else, *he pays no attention,* or *has secrets he cannot share. He is never home. A scientist should not marry. No one wants to be such a scientist* or *to marry him.*

THE POSITIVE. The scientist *is a very intelligent man—a genius* or *almost a genius. He has long years of expensive training —in high school, college,* or *technical school,* or perhaps even beyond, during which *he studied very hard. He is interested in his work and takes it seriously. He is careful, patient, devoted, courageous, openminded*

He is a dedicated man who works not for money or fame or self glory, but—like Madame Curie, Einstein, Oppenheimer, Salk —for the benefit of mankind and the welfare of his country.

One cannot claim, of course, that science teachers are solely responsible for the picture delineated in the study. After all, the children are in school for less than half their waking hours for half the days of the year for only a few years. Science teachers have the pupils only a modest fraction of even the school day. So we should not credit them with, or blame them for, all the faults or accomplishments of society. Yet the science teacher is the major person who can do something about setting the picture as right as it can be. He is the link between science (and scientist) and his students. He is often the only link.

[1] Margaret Mead and Rhoda Métraux, "Image of the Scientist Among High School Students—A Pilot Study," *Science, 126,* 384, Aug. 1957. This illuminating study is quoted in *full* in this chapter, beginning on p. 451, to prevent distortion.

creative intellectual work by scientists is seen clearly, our image of him is blurred by the technical procedures through which scientific ideas are applied.

The intellectual side. The general philosophical impact of science upon how we look at the world and man in it is also shaped by scientific discoveries and ideas. The Copernican proposal of a sun-centered system of the planets touched off, or fitted into, the intellectual revolution of the Renaissance. This had a great impact upon philosophical and theosophical ideas. Newton's concept of universal gravitational attraction between every particle was translated by Locke and then applied by Paine and Jefferson in the political sphere. Classical physics, which involved a "determined" world, fitted with the political and economic concepts of past times. As yet "modern physics," with its emphasis on quanta and probability, has not permeated the thinking of most people, but it probably will. Certainly the theory of evolution had a major social impact, and so did the theory of relativity.

There was a time when science (as natural philosophy) was part of every "educated" man's education, when "sciencing" was just one of the activities of thinking people. As the field grew, and as technology seemed to obscure theory in the minds of many, science was divorced from the rest of the "liberal arts." And it has not yet been readmitted to full, respectable status among our intellectuals.

Nowadays, when everyone is aware of the strategic importance of science, will this trend reverse? As more young people study science, will they think only in terms of the obvious, practical applications of science? Or will they come to know also the philosophical base of science, "what it's all about," the joys of this particular kind of intellectual and creative endeavor?

What picture do high school students today have of science and scientists? In a study [2] of over 300 young people who intended to make a science their career, 283 wrote essays which parallel closely the positive image of the scientist presented on p. 448; indeed, they were even more favorable, if not more realistic. But this is to be expected of those who intend to live as scientists.

What of those who do not plan to become scientists? What of those upon whom scientists depend for support? What of those young people, in the vast, vast majority, who tend not to become scientists, those upon whom the science teacher depends for his support? Toward an indication of the kind of perspective in which this image of the scientist tends to be built up, we quote in full a study by Mead and Métraux. Note carefully the qualifications which the authors of the study have set up and the nature of their conclusions.

A portrait of the scientist—by high school students [3]

Prefatory note [by the editors of *Science*]

There is a great disparity between the large amount of effort and money being devoted to interesting young people in careers as scientists or engineers

[2] P. F. Brandwein, unpublished work.
[3] Margaret Mead and Rhoda Métraux, *op. cit.*, pp. 384 ff. Quoted in full, by permission.

do graduate with such a major. Engineering schools also graduate only about half of their entering classes. Even in college the commitment to science is not firm or the student is not successful, with the result that the potential scientist pool shrinks yet more. After the freshman year in college very few students shift *into* a science program, while many shift *out*.

Essentially then we have, from the tenth grade onward, a steady decrease in the number seriously considering science as a possible career. To increase the number eventually committed to science requires an increase of the number who are *not anti-science* in the early grades. We must teach so that the time of a decision is postponed as long as possible and is based on relevant experience and knowledge. This places a great responsibility on teachers, particularly on those in the elementary and junior high schools. This does not mean, we repeat, teaching the content of physics, chemistry and biology in the lower grades; it does mean, we think, that methods of teaching science need be improved so that more young people of ability try science in the later grades and in colleges. This book has been concerned with these methods.

The need for citizens prepared to live in a scientific world

Science teaching does not begin or end with the "production" of scientists. In this country there are now about 2 million people classed as professionals, and these include 1 million scientists, doctors, engineers, science teachers, dentists, and nurses. Our total population is more than 170 million, and by 1975 it will be close to 200 million. All these people live in a world where:

During the first half of this century some 25 years have been added to the average life span of the children born in the U. S.

During the first half of the century man has taken to the air; a trip across country which in 1900 took nearly 175 hours is now completed between sunrise and sunset.

During the first half of the century everything man wears and eats has been improved by scientific work.

During the first half of the century there has been a major revolution in our most fundamental ideas about the universe, and the beginning of such a revolution in our understanding of life itself.

During the second half of the century—????

The material side. We are all heavily dependent upon, and indebted to, past performances of scientists. Our land occupies only 6 per cent of the earth's surface and has some 7 per cent of its population. Yet we own 31 per cent of all radios and television sets, use 58 per cent of the world's telephones, and drive 76 per cent of the world's automobiles. We produce 40 per cent of all the world's electrical power and publish 27 per cent of the world's newspapers. Clearly the scientist is behind all this. Unless in school the significance of

Objectives. Our specific objectives in this study were to learn the following.

1. When American secondary-school students are asked to discuss scientists in general, without specific reference to their own career choices or, among girls, to the career choices of their future husbands, what comes to their minds and how are their ideas expressed in images?

2. When American secondary-school students are asked to think of themselves as becoming scientists (boys or girls) or as married to a scientist (girls), what comes to their minds and how are their ideas expressed in images?

3. When the scientist is considered as a general figure and/or as someone the respondent (that is, the student writer) might like to be (or to marry), or, alternatively, might not like to be (or to marry), how do (a) the positive responses (that is, items or phrases, not answers) cluster, and (b) the negative responses (that is, items or phrases) cluster?

4. When clusters of positive responses and clusters of negative responses are compared and analyzed, in what respects are the two types of clusters of responses (a) clearly distinguishable, and (b) overlapping?

5. Is a generally positive attitude to the idea of science, an attitude which we are spending a great deal of money and effort to create, any guarantee of a positive attitude to the idea of science as a career?

Selection of respondents. Two separate samples of respondents were used in the study: sample A, a nation-wide sample of high schools, and sample B, a sample of high schools with widely different economic and educational characteristics.

Sample A consisted of 132 public high schools (including one junior high school) that were selected from schools associated with the Traveling High-School Science Library Program sponsored by the National Science Foundation and administered by the American Association for the Advancement of Science. Of these, 118 were drawn from the high schools that participated in this program, and an additional 14 from schools that qualified for the program but could not be included in it.

Sample B consisted of 13 special schools: four parochial schools, eight preparatory schools, and one public science high school. All these were from the eastern seaboard, selected to provide contrasts in educational and economic level to the smaller public high schools in the nation-wide sample (sample A). Sample B was collected after the homogeneity of the nation-wide sample had been ascertained.

The total enrollment of the schools participating in the study was 48,000. Schools with an enrollment of less than 300 students were asked to have each student complete one form; schools with an enrollment of more than 300 students were asked to complete 300 forms. The total sample (sample A and sample B) is drawn from the essays written by approximately 35,000 students, and the essays were kept together by the class, grade, and school from which the essays came.

The sample was randomized by drawing envelopes of these replies in groups that included three schools in one state, or three tenth grades, or all the separate classes in three schools, so that no essay was ever separated from the context in which it had been written.

Data-gathering instruments. We asked each high-school student respondent to write a brief essay on a topic set by an incomplete sentence which was printed at the top of a page, on which provision was also made for giving the school, the grade, the class or section, the age, and sex of the respondent.

Three different forms were constructed, each with a different incomplete

and the small amount of information we have on the attitudes those young people hold toward science and scientists. The Board of Directors of the AAAS has on several occasions discussed this disparity and the desirability of learning more about what high school students actually think of science and scientists. This paper is one result of those discussions. Hilary Deason, director of the association's Traveling High School Science Library Program, made all of the arrangements with the high schools and supervised the collection of the students' essays. The analysis of those essays and the preparation of this report were the responsibility of the two authors, Margaret Mead and Rhoda Métraux. Dr. Mead is associate curator of anthropology, American Museum of Natural History, New York, and Dr. Métraux is a research fellow at Cornell Medical College, New York.

IMAGE OF THE SCIENTIST AMONG HIGH SCHOOL STUDENTS—A PILOT STUDY

Margaret Mead and Rhoda Métraux

This study is based on an analysis of a nation-wide sample of essays written by high school students in response to uncompleted questions. The following explanation was read to all students by each administrator. "The American Association for the Advancement of Science,* a national organization of scientists having over 50,000 members, is interested in finding out confidentially what you think about science and scientists. Therefore, you are asked to write in your own words a statement which tells what you think. What you write is confidential. You are not to sign your name to it. When you have written your statement you are to seal it in an envelope and write the name of the school on the envelope. This is not a test in which any one of you will be compared with any other student, either at this school, or at another school. Students at more than 120 schools in the United States are also completing the statement, and your answer and theirs will be considered together to really find out what all high school students think as a group of people."

In general, the study shows that, while an official image of the scientist—that is, an image that is the correct answer to give when the student is asked to speak without personal career involvement—has been built up which is very positive, this is not so when the student's personal choices are involved. Science in general is represented as a good thing: without science we would still be living in caves; science is responsible for progress, is necessary for the defense of the country, is responsible for preserving more lives and for improving the health and comfort of the population. However, when the question becomes one of personal contact with science, as a career or involving the choice of a husband, the image is overwhelmingly negative.

This is not a study of what proportion of high school students are choosing, or will eventually choose, a scientific career. It is a study of the state of mind of the students, among whom the occasional future scientist must go to school, and of the atmosphere within which the science teacher must teach. It gives us a basis for re-examining the way in which science and the life of the scientist are being presented in the United States today.[4]

* To control any possible influence which the wording of this statement might have, part of sample B was collected without reference to the association. No difference in the formulation of the replies was found when the association was mentioned and when the association was not mentioned.

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[a] Italics ours

wide set of images—rather than of answering questions on which or how many students may be expected to respond in a given way—a qualitative study is preferable.

The identification of the pattern in any large sample of essays and of the cognitive and emotional processes which underlie the attitudes reported by individuals is best accomplished by trained behavioral scientists. Because any one analyst, no matter how well trained, may have some blind spots and biases, and because analysts differ in their types of disciplined perception, we had six different analysts work independently with six subsamples of the total sample drawn from different states. Because one kind of material may be more useful than another in outlining a given area, we used—in addition to the essay samples from the 35,000 students—a variety of other kinds of materials as well.

We are assured that we have identified important themes in the material by the multiplicity of independent analyses and by the use of a variety of data. We are assured of the validity of our conclusions by a comparison of the independent work of the analysts and by the agreement on materials from different parts of the country.

Stages in analysis and validation. The stages in analysis and validation were as follows.

1. Sets of data were drawn from the main corpus by envelopes of answers, each set consisting of from 200 to 500 protocols, all from one state and including envelopes of answers to all three forms. Each of the six senior consultants was given a set of data. They worked in complete independence of one another until they met in conference to pool their results in discussion. This discussion was transcribed. The discussion indicated that the analysts were in agreement on the homogeneity of the attitudes found in the materials from different sections of the country. On the basis of this preliminary working of the material from sample A, further collections for sample B (including provision for a control on the use of the words *American Association for the Advancement of Science*) were planned and carried out.

2. A detailed pattern analysis was performed on 1,000 essays, chosen to represent both the homogeneous nation-wide sample of public schools (sample A) and the highly diversified schools (sample B). This analysis of responses (that is, items, phrases) both checked on the patterns identified by the senior analysts (among whom was included the analyst who made the detailed pattern analysis) and provided additional understanding of the patterns.

In making this analysis, essays from classes and schools were still kept together, so that each respondent could be placed and each essay could be placed within the major preoccupations of a class or a school. So some schools provided particularly clear material on the dichotomy between science as a subject for study and the personality of the scientist, or on ways in which an increasing sense of inadequacy was reflected in the rejection of science as a career. Everywhere it was possible to follow the divergent interests of boys and girls—as with the boys' interest in an active outdoor life and the girls' interest in the humanitarian aspects of medicine—but there were underlying assumptions shared by both sexes, such as the great importance of personal interests as a basis for career or marriage choice.

3. Fourteen graduate students were asked to report on smaller independent samples of essays. Graduate students were also enlisted to make collections of visual materials related to the image of the scientist in the culture of the United States today. Examples of this collection are illustrations from selected periodicals which present images of scientists, children's drawings made in response to

sentence. Each of these three sentences was chosen to elicit one major aspect of the image of the scientist.

Only one form was used in any one school,† but the forms were so distributed that each form was used by at least one school in each state. These three forms are as follows

Form I Complete the following statement in your own words. Write at least a full paragraph, but do not write more than a page.

When I think about a scientist, I think of

Form II: If you are a *boy*, complete the following statement in your own words.

If I were going to be a scientist, I should like to be the kind of scientist who

If you are a *girl*, you may complete either the sentence above or this one.

If I were going to marry a scientist, I should like to marry the kind of scientist who

Form III: If you are a *boy*, complete the following statement in your own words.

If I were going to be a scientist, I would not like to be the kind of scientist who

If you are a *girl*, you may complete either the sentence above or this one.

If I were going to marry a scientist, I would not like to marry the kind of scientist who

Use of the three forms made it possible to distinguish between answers giving official versions of the image of the scientist and those involving the respondents personally, and the use of two forms of the personal question provided material on the links between negative and positive images, since many answers included responses relevant to both. Experience has shown that the way in which a question is phrased—that is, with a positive or with a negative emphasis—affects the phrasing of the answers by the respondents.

Analysis of material and problems of validation. This study is based on qualitative data. The material reflects the way individuals feel and think about a subject, as well as whether they will answer questions about the subject in the affirmative or the negative. The use of quantitative data, gathered primarily to count the number of individuals in any given group who will respond in one way or in another, is the more desirable technique when one is interested in whether individuals will agree or disagree with some stated opinion, rather than how they feel or why they feel as they do. The check marks or brief responses gathered by quantitative studies are generally too sparse in the expression of feeling and imagery to permit the definition, or the redefinition, of shared attitudes; in such studies, attitudes which are assumed to exist are built into the questions.

The relative value of qualitative and quantitative studies has been debated in the behavioral sciences for some time. A resolution generally accepted at the present time is that the qualitative study is the method of choice for generating hypotheses, and the quantitative study the method of choice for testing hypotheses.‡ When the problem is one of delineating a shared aspect of a society-

† In six of the schools included in sample B, all three forms—to be used by different classes—were sent to the same school.

‡ There are a number of different quantitative studies of the broader subject under way: those directed by H. H. Remmers in the Division of Educational Reference at Purdue University, on high-school students' attitudes toward science; a study at the Survey Research Center at the University of Michigan on attitudes of the public toward science writing, two studies under the Science Manpower Project at Teachers College, Columbia University, one by Hugh Allen, on "Attitudes Toward Science and Scientific Careers: A Research Inventory for New Jersey High School Seniors," and a second by Frances Hall, on science teachers' attitudes toward science. The Interim Committee on Studies on the Social Perception of the Satellite Program and Personnel, under the chairmanship of Donald Michael of Dunlap Associates, Stamford, will also cover some overlapping areas

Science means *doing* and *making*: *hard work*—not imagination—is the source of knowledge and the means of accomplishment.

The focus of science is upon the present. The past is important only as it is left behind (*without science we would still be living in caves*) and the future as a foreseeable goal (when we *find a cure for heart disease, see if there is life on Mars, discover new fuels . . .*). But as the past closes in behind us, the future opens to the curious (*there is still so much to discover*) into the yet unknown.

In thinking about science, different sorts of linked images occur which may be bracketed together when science is rejected or may be included when positive preference is expressed for one of a pair. So, science may be *theoretical* or *applied*, and either of this pair can be seen as more of a whole and be accepted (that is, the man in the laboratory is visualized as working through the whole problem; or the engineer can see the finished road), while the other is seen as partial and is rejected (that is, the engineer is visualized as working only on the end-product; or the man in the laboratory never sees the plan carried out). Likewise, science can be carried out *in the laboratory* or in a *far away place;* it may involve large-scale action (*traveling, digging, exploring, constructing, flying through space . . .*) or the skills of fine detail (*gazing through a telescope, poring over a microscope, dissecting, solving equations . . .*). The goals of science may be humanitarian (*working to better mankind, finding cures, making new products,* developing *programs for atoms for peace . . .*), or, in contrast, they may be either individualistic (*making money, gaining fame and glory . . .*) or destructive (*dissecting, destroying enemies, making explosives* that *threaten* the *home,* the *country,* or *all mankind . . .*).

Since, by implication, science is the source of unlimited power, its practitioners should have the highest and the most selfless motivations to use only its constructive possibilities only constructively—*for* the *welfare of their country* and the *betterment of people, the world,* and *all mankind.*

THE SCIENTIST: *the shared image* ||

The scientist is a man who wears a white coat and works in a laboratory. He is elderly or middle aged and wears glasses. He is small, sometimes *small and stout,* or *tall and thin. He may* be *bald. He* may *wear a beard,* may be *unshaven* and *unkempt. He* may be *stooped and tired.*

He is surrounded by equipment: test tubes, bunsen burners, flasks and bottles, a jungle gym of blown glass tubes and weird machines with dials. The sparkling white laboratory is full of sounds: the bubbling of liquids in test tubes and flasks, the squeaks and squeals of laboratory animals, the muttering voice of the scientist.

He spends his days doing experiments. He pours chemicals from one test tube into another. He peers raptly through microscopes. He scans the heavens through a telescope [or *a microscope!*]. *He experiments with plants and animals,*

|| A few of the more mature students realize that this picture is stereotyped and incomplete. So, for instance, having described the scientist as the "man in the white coat," students continue: "On second thought—he *might* equally well be seining a small stream, feeding facts into an electronic computer, or injecting a radioactive fluid into the veins of a monkey" (boy, 17, 12th grade). "I realize that there is more than microbiology [that is, the *man in the* white coat] to science. Therefore, I think of the atom, and somehow always of old men, working on various bombs and reactors. When I think of the use of atoms for peace, I think of young men working in offices. I don't know why" (girl, 14, 10th grade). "At the word *science,* I can imagine so much. The scope is unlimited and I sometimes do not connect the two words *science* and *scientist* any further than the laboratory. But if I could put the two together, a scientist would become more of an adventurer, a romanticist, than a figure who is nothing but a human IBM machine" (boy, 15, 10th grade).

the instruction "Draw a scientist," and the entire pictorial file from the public relations office of a pharmaceutical company.

4. Still another set of student essays from sample A was given to a seventh senior consultant, who had had no previous contact with any of the materials. Since she had not been involved in the earlier stages of the study, she could bring a fresh point of view to the final conference on the basis of which the report was written.

5. A final conference of the senior consultants was held, at which the preliminary findings were again reviewed, and the findings presented in this article were discussed in detail. There was general agreement that the findings effectively represented the data.§

The composite image. In reading the following composite statements, it is important to realize that they do not represent literary descriptions written by the analyst, but rather composites of the responses made by the students in their essays, so that each "composite image" is to be understood as being something like a composite photograph which emerges from a very large number of superimposed photographs. Each phrase (response) both stands for a family of phrases (responses) which were used throughout the essays and is itself a recurrently used phrase (response). The phrases have been grouped in relation to themes, as they occur in the essays, but reference to the themes might occur in any order in the essays. It is important to realize that in organizing for presentation here the positive and the negative versions of the composite image of the scientist, the analyst has separated out from the answers the positive phrases (responses), on the one hand, and the negative phrases (responses), on the other hand, as an analytic device, whereas in the essays both occur—or may occur—together in a variety of combinations.

Before the image of the scientist is discussed, it will be useful to look at the way "science" appears in these essays. In the following composite statements, italics indicate the words and phrases (responses) used; detailed examples are given in parentheses, and explanatory notes in square brackets.

SCIENCE: *Science is a very broad field* which may be seen as a single unit (*science is very important*, or *I am not interested in science*), as a melange (*medicine and gas and electric appliances*), or as composed of entities (*biology* and *physics* and *chemistry* . . .) linked together by the personality of the *scientist*.

Science is natural science with little direct reference to man as a social being except as the products of science—*medicine* and *bombs*—affect his life. The subjects of science are *chemistry* and *physics* (*laboratories, test tubes, bunsen burners, experiments* and *explosions, atomic energy, laws* and *formulas* . . .), *biology-botany-zoology* (*plants* and *animals* [that is, as materials for laboratory work], *microscopes, dissection, the digestive system, creepy* and *crawly things* . . .), *astronomy* (*the moon, stars, planets, the solar system, outer space, astronomers, astrologers* [sic], *telescopes, space ships* . . .), *geology* (*the earth, rocks, mines* and *oil wells, out of doors* . . .), *medicine* (*cures for TB, cancer, heart disease,* and *polio, research, serums* . . .), *archeology* (*exploration, ancient cities, early man, fossils, digging* . . .). *Mathematics* is not a science but a tool and a measure of scientific aptitude.

The methods of science are *research* and *experimentation, invention, discovery, exploration, finding out new things* and *new ways of improving old ones.*

§ For assistance in this study through the Institute for Intercultural Studies, which cooperated with the American Association for the Advancement of Science, we wish to thank Ruth Bunzel, Edith Cobb, Natalie Joffe, Martha Wolfenstein, Mark Zborowsky, also graduate students in Columbia University anthropology courses GS 271-2 and GS 198, and, for criticism of the report, Robert Weiss of the Survey Research Center, University of Michigan.

He neglects his family—pays no attention to his wife, never plays with his children. He has no social life, no other intellectual interest, no hobbies or relaxations. He bores his wife, his children and their friends—for he has no friends of his own or knows only other scientists—with incessant talk that no one can understand; or else *he pays no attention* or *has secrets he cannot share. He is never home. He is always reading a book. He brings home work and also bugs and creepy things. He is always running off to his laboratory. He may force his children to become scientists also.*

A scientist should not marry. No one wants to be such a scientist or *to marry him.*

DISCUSSION

The "official" image of the scientist—the answer which will be given without personal involvement—which was evoked primarily in Form I, but which recurs in the answers to all three forms, is a positive one.

The scientist is seen as being essential to our national life and to the world; he is a great, brilliant, dedicated human being, with powers far beyond those of ordinary men, whose patient researches without regard to money or fame lead to medical cures, provide for technical progress, and protect us from attack. We need him and we should be grateful for him.

Thus if no more than Form I had been asked, it would have been possible to say that the attitude of American high-school students to science is all that might be desired.

But this image in all its aspects, the shared, the positive, and the negative, is one which is likely to invoke a negative attitude as far as personal career or marriage choice is concerned. While the rejection in the negative image is, of course, immediately clear, the positive image of very hard, only occasionally rewarding, very responsible work is also one which, while it is respected, has very little attraction for young Americans today.** They do not wish to commit themselves to long time perspectives, to dedication, to single absorbing purposes, to an abnormal relationship to money, or to the risks of great responsibility. These requirements are seen as far too exacting. The present trend is toward earlier marriage, early parenthood, early enjoyment of an adult form of life, with the career choice of the man and the job choice of the woman, if any, subordinated to the main values of life—good human relations, expressed primarily in terms of the family and of being and associating with the kind of human being who easily relates to other people.

To the extent that any career—that of diplomat, lawyer, businessman, artist, aviator—is seen as antithetical to this contemporary set of values, it will repel male students as a career choice and girls as a career for their future husbands. But it is important to see also the particular ways in which the image of a scientific career conflicts with contemporary values. It divides girls and boys. The boys, when they react positively, include motives which do not appeal to the girls—adventure, space travel, delight in speed and propulsion, the girls, when they react positively, emphasize humanitarianism and self-sacrifice for humanity, which do not appeal to the boys. The girls reject science, both as a possible form of work for themselves, concerned with things rather than with people, with nonliving things (laboratory animals, not live animals, parts of anatomy, not living children), and for their husbands, because it will separate them, give their husbands absorbing interests which they do not share, and involve them in various kinds of danger. In earlier periods, when career choices and marriages occurred

** In this statement, we draw not only on the attitudes in this study, but on a wide variety of other materials on the attitudes of contemporary young Americans.

In contrast, other activities are defined as nonscientific because they are absorbingly interesting: "watching things grow that I have planted," or "working on my hot rod car."

The role of the teacher—as reflected in the comments of a whole class—is an exceedingly interesting one. The disliked teacher is personalized and vivid; the teacher who has obviously been very successful and has caught the imagination and enthusiasm of the whole class does not emerge as a person at all but, instead, sinks into the background of good classroom conditions, together with "good laboratory equipment." Special aspects of the disliked teacher are commented on in detail. He may be described as an outsider, a stranger, with unusual habits of dress and manner, who does not know his subject well, who cannot talk about anything but his subject, who lives alone without the slightest tie to the community, who is "stuck up and who is too busy for anyone but himself." It is easy to see how the only male teacher in the school presents special problems to the boys, if he himself is a figure they reject, and how easily the sphere of work for which he stands may be rejected also. So one boy writes, "Anyone who digs our teacher's gab is a square as well as being queer." Some of these consequences undoubtedly flow from the convention in the United States that, ideally, science should be taught by men, with the result that men who might be more successful teachers in some other field are forced into teaching a subject which they dislike and in which they have no special competence. Similarly, foreigners and refugees—if male—may have a better chance to get positions as mathematics and science teachers than they have in other fields.††

The significance of the lack of particular mention of the good science teacher is equally important, for it is related to the lack of invocation of authority by the students, who state their opinions about science—even those obviously related to a particular teacher—as their own. Only when they disagree, when they wish to attack the current image of science as a good thing from a minority position—that is, from the viewpoint of some fundamentalist religious position which they accept—do they invoke authority. It is related also to the situation in American culture where, through generations, there has been a break between immigrant parent and native-born child. In this new setting, the European tendency for children to identify with the personality and occupation of the parents has been replaced by a tendency to follow the style set by members of one's own generation, especially those in one's own local school clique.

In the classroom, a disliked fellow student who is regarded as a future scientist may also be described in some detail, as students say they do not want to be the kind of scientists who "go about with their noses in a book, looking superior." But in those classrooms where everyone has been committed to the joy of some experiment or project, no individuals emerge; it is impossible to say what is the sex, age, nationality, and personality of the teacher.

In summary, it may be said that where science teaching is successful, the teacher has created a situation in which his or her (one does not know which) personality sinks into the background, and in which no one student stands out as so especially gifted and preoccupied as to rouse annoyance in the class. Stu-

†† The other side of this picture is sometimes seen in comments made by foreigners who have entered the sciences because Americans think they require less of a knowledge of the culture, and who because of their science training can get teaching positions in the schools. After a year or two of teaching in small-town schools, the foreign-born teacher flees back to the cities where he has friends or at least can live anonymously. (Based on life-history data from Chinese informants in the Chinese section of the Study Program in Human Health and the Ecology of Man, New York Hospital–Cornell Medical College, New York.)

later the girls' attitudes might not have mattered so much; they are very important today on the one hand, because girls represent a principal untapped source of technical skill and on the other hand, because, with present adolescent social patterns, paired boys and girls spend a great deal of time discussing the style of their impending marriage and parenthood and the relationship of the boy's career choice to the kind of home they will have.

The image of the scientist's relationship to money also presents a problem, in a period of full employment, to young people who think that an adequate income is something that should be taken for granted. The scientist is seen as having an abnormal relationship to money. He is seen either as in danger of yielding to the temptation of "money and fame," or as starving and poor because of his integrity. The number of ways in which the image of the scientist contains extremes which appear to be contradictory—too much contact with money or too little, being bald or bearded; confined work indoors, or traveling far away, talking all the time in a boring way, or never talking at all—all represent deviations from the accepted way of life, from being a normal friendly human being who lives like other people and gets along with other people.

Specific indications about the teaching of science

From the standpoint of teaching, *it is important to realize how the present image of scientific work lacks any sense of the delights of intellectual activity;*[8] the scientist works patiently and carefully for years, and only when he finds out something does he shout with joy. This lack of any sense that intellectual activity is rewarding in itself can be related to the lack of any mention of living things, plant, animal, or human, in the materials with which the scientist is believed to work. Plants and animals appear only as dead objects for dissection; the human body, as organs or systems studied in the laboratory and treated in medicine, whole human beings appear only as the dead denizens of dead and buried cities, and most of the scientists about whom they read are also dead. The lack of any sense of enjoyment can also be related to the central role given to mathematics as a tool, without any emphasis on the delights of observation, as in early natural history studies or in the perception of regularities and connections in the world around them, or between themselves and the world around them.

Because the materials were analyzed class by class and school by school, the study has also yielded, as a by-product, certain sidelights on science teaching: on the importance of participation as opposed to passive watching, on the role which the personality of the teacher plays in attitudes toward science, on the effect on the rest of the class of the presence in it of one type of exceptionally gifted child.

One of the most recurrent responses is an expression of active boredom, the phrase, "I am not interested in science," or in a particular science course (chemistry or physics), followed occasionally by highly emotional expressions of fury and hatred of particular activities which are being demonstrated. "Interest" and "active enjoyment" seem to be so closely related that the student seated in a classroom who has to watch things being poured from one test tube to another or listen to a string of unrelated facts becomes permanently alienated. General science courses seem to be the ones in which this attitude toward science is characteristically invoked, except when a gifted teacher gives it some special emphasis. When mathematics is seen as the key ability on which all future scientific work is based, not liking and not being able to do mathematics become a specially weak point in the circle of the students' interests.

[8] Italics ours.

5. Emphasize the need for the teacher who enjoys and is proficient in science subjects, irrespective of that teacher's sex; this would mean that good women teachers could be enlisted instead of depending on men, irrespective of their proficiency. Since it would seem that the boys do not need to identify with an adult male as a teacher, this should leave us free to draw on women as a source of science teachers.

6 Change the teaching and counseling emphasis in schools which now discourage girls who are interested in science. This would have many diffuse effects: on the supply of women teachers and of women in engineering, on the attitudes of girls who are helping boys to choose careers, and on the attitudes of mothers who are educating their small children in ways which may make or mar their ability to deal with the world in scientific terms.

7. De-emphasize individual representatives of science, both outstanding individuals like Einstein—whose uniqueness simply convinces most students that they can never be scientists—and the occasional genius-type child in a class. (This type of child, who represents only one kind of future scientist and who is often in very special need of protection from the brutalities of his age mates, should probably be taken out of small, low-level schools, and placed in a more protected and intellectual environment.) Instead, emphasize the sciences as fields, and the history of science as a great adventure of mankind as a whole. (The monotonously recurrent statement "if it weren't for scientists we would still be living in caves" is an insult to the memory of millions of anonymous men who have—each in his way—made further advances possible.)

8. Avoid talking about *the scientist, science*, and *the scientific method*. Use instead the names of the sciences—biology, physics, physiology, psychology—and speak of what a biologist or a physicist does and what the many different methods of science are—observation, measurement, hypotheses-generating, hypotheses-testing, experiment.

9 Emphasize the life sciences and living things—not just laboratory animals, but also plants and animals in nature—and living human beings, contemporary peoples, living children—not the bones and dust of dead cities and records in crumbling manuscripts. Living things give an opportunity for wonder and humility, necessarily less present in the laboratory where students deal with the inanimate and the known, and contact with living things counteracts the troubling implication that the scientist is all powerful.

Conclusion. This report is not in any way a statement of the proportion of high school students who will choose science as a career. It is a discussion of the state of mind of fellow-students, among whom the occasional future scientist must go to school, of the degree of personal motivation necessary to commit oneself to science, and of the atmosphere within which the science teacher must teach. Since most high-school students' attitudes closely reflect those of their parents, it is also an indication of the climate of opinion in which parents may be expected to back up their children in choosing science as a career, citizens may be expected to vote funds for new laboratories, and voters may be expected to judge Congressional appropriations for science education.

Devastating, illuminating, challenging, irritating, exciting—all these terms could be used to describe this study by Mead and Métraux. Certainly there are many sobering facts and conclusions here for teachers to ponder. As we said earlier, the science teacher is not solely responsible for this image of the scientist. The advertisements in magazines, newspapers, on TV and billboards, all contribute to the distortion of the image of the scientist. So do cartoons and the often deprecating tone of newspaper articles about science and scientists.

dents and teacher appear to have worked as a group, accepting science as a part of *their* lives, preoccupied with no specific identified individuals

RECOMMENDATIONS

Mass media Straight across the country there is a reflection of the mass media image of the scientist which shares with the school materials the responsibility for the present image Alterations in the mass media can have important consequences in correcting the present distorted image if such changes are related to real conditions Attempts to alter the image, in which the public relations department of a particular company represents its research personnel with crew cuts and five children, may improve the recruitment program of single companies but do so only at the expense of intensifying the negative aspects of the image for the country as a whole

What is needed in the mass media is more emphasis on the real, human rewards of science—on the way in which scientists today work in groups, share common problems, and are neither "cogs in a machine" nor "lonely" and "isolated Pictures of scientific activities of groups, working together, drawing in people of different nations, of both sexes and all ages, people who take delight in their work, could do a great deal of good

The mass media could also help to break down the sense of discontinuity between *the scientist* and other men, by showing science as a field of endeavor in which many skills, applied and pure, skills of observation and of patient, exact tabulation flashes of insight, delight in the pure detail of handling a substance or a material, skills in orchestrating many talents and temperaments, are all important This would help to bring about an understanding of science as a part of life, not divorced from it, a vineyard in which there is a place for many kinds of workers

The schools The material suggests the following changes which might be introduced in educational planning

1 Encourage more participation and less passive watching in the classroom, less repeating of experiments the answers to which are known; give more chance to the students to feel that they are doing it themselves. A decrease in the passive type of experience found in many general science courses seems particularly necessary

2 Begin in the kindergarten and elementary grades to open children's eyes to the wonder and delight in the natural world, which can then supply the motive power for enjoyment of intellectual life later. This would also establish the idea of science as concerned with living things and with immediate—as contrasted with distant—human values

3. Teach mathematical principles much earlier, and throughout the teaching of mathematics emphasize nonverbal awareness. ‡‡ let children have an opportunity to rediscover mathematical principles for themselves.

4. Emphasize group projects; let the students have an opportunity to see science as team work, where minds and skills of different sorts complement one another.

‡‡ Studies of the College Entrance Examination Board Commission on Mathematics and the University of Illinois Committee on School Mathematics give promise of bringing about improvement in mathematics instruction A study of junior high school mathematics will be undertaken at the University of Maryland this fall There is more to be done, especially in the elementary grades, and state departments of education should be encouraged to establish state committees which can determine how work now in progress at the national level can be made effective in local schools. The Poloidiblocs, developed by Margaret Lowenfeld of the Institute of Child Psychology, 6 Pembridge Villas, London, W. 11, are an important addition to the equipment for teaching young children mathematics.

personally enjoyable. In essence, the place of science for all is becoming a *fait accompli*, forced upon schools and teacher by two apparently contradictory elements:

1. More young people, representing most of the range in abilities and interests, tend to remain in school longer.
2. There is a greater need for scientists.

General science has become a course in which the basis of general education is applied. To a great extent this is true also of biology. In chemistry and physics, there is still greater concern for the subject material as a possible basis for careers in science. These courses have kept their air of specialization; nevertheless, changes are beginning to appear.

The need for science teachers

Science teaching in the United States has been successful, so successful in fact that each year many thousands of young men and women choose careers in science and enroll for a difficult sequence of collegiate courses. *Each year* more than forty five thousand graduate from college as majors in science and engineering. In addition, over three thousand complete the arduous program for a doctorate degree in these fields. The rapid expansion of our laboratories and technical industries exhibits the competence of these graduates.

Paradoxically, this very success has turned increased attention upon the improvement of science instruction all through the schools, for "nothing breeds success like success." We enjoy the benefits of science; we want more of the same. Science teaching has, at least in some ways, been successful.

In the previous chapters we have indicated that there is, and probably always will be, room for improvement in both the intent and the content of our science teaching. The social responsibility of the science teacher is now recognized. No longer will "good enough" pass inspection; we must strive for "ever better." The teachers' obligations to a diverse group of children, increasing school enrollments, and the changing setting of science in the culture cannot be dismissed casually.

The growth of science enrollments

With a large proportion of the current children enrolled in school (forty million pupils), we may forget that nearly one-half of the adult population never attended high school. Raised in times when schooling was a rare social privilege, half our adults never had any contact with a science teacher.

In 1890 only one child in fourteen, aged 14 to 17, was enrolled in any secondary school and eligible for such science courses as were offered. In 1955 over three out of four in this age group were in school. With the diversification of pupil abilities and interests in school has come a diversification of elective

These attitudes are widespread throughout the public. The science teacher alone cannot be expected to overcome them all or to do it alone. Yet the science teacher is one of the prime interpreters of the way of the scientist. His own attitudes, the way he teaches, the intent and content of his courses, all lend support to the image of the scientist and the scientific enterprise which the youngster conjures up

This whole book has been aimed at helping teachers enable children to "sense the delights of intellectual activity," and to see how the real world of living things and operating devices can be the source of stimulating study through active participation For the great mass of students the effective teacher, the guide to learning activities, becomes a blur, with the student's enthusiasm and glow directed toward the subject areas in which he is involved Much the same must be recognized as the role of effective parents whose particular supporting actions are rarely recalled by their children, even while the aura of parental warmth and interest are long treasured.

Mead and Metraux suggest less emphasis on the "very great" scientists At first this evokes disagreement until we realize that all too often these men are presented as remote geniuses who should be idolized for their accomplishments which often are incomprehensible to the students In fact, these great men are often presented as the source of the information, theories, and equations which cause the student so much difficulty. No wonder they are looked on with dismay and awe, and sometimes, we suspect, a bit of distaste. This immediately suggests that the scientific greats be presented as human beings (some of them young, very young) who made mistakes, had political troubles, tried to earn an adequate living, and behaved much like the rest of us. Names, dates, and great discoveries are certainly not enough to develop such impressions of great scientists.

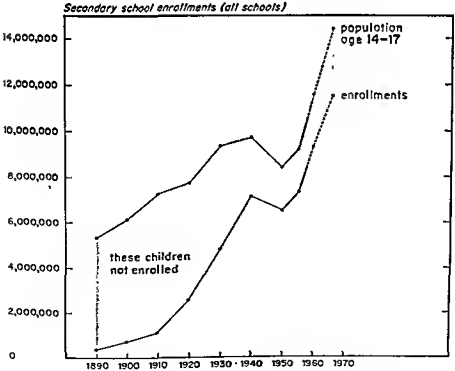
All this underscores our earlier conclusion that the attitudes students develop toward science and scientists are far more important in their later life than are the particular bits of information they can recall. Yet, generally speaking, science teaching in the secondary school is fact-ridden and oriented toward "college preparation." The vast majority who are not going to college gets, as does the collegiate minority, an image of science which is grossly distorted. Science is "right," is "accurate," "always works" because they see demonstrations which always "come off"; conclusions are reached with finality, and texts support this limited view so that the student can say: "Biology, oh, I *had* it in high school." Science is a closed system of knowledge which only geniuses can extend What a travesty such an impression is!

Fortunately this approach to science teaching is changing. The place of science in general education for all, as a creative activity of the human mind in an effort to "make sense out of the booming buzzing world," is gaining As such, science teachers look toward the development of human beings who are led to experience science as part of human enterprise and aspiration. Such a view does not neglect the potential scientist among the children, but actually is more likely to keep his interests within science which he and his peers find

TABLE 21-1 *Growth of population aged 14-17, and of secondary school enrollments 1889 to 1965-66* *

YEAR	POPULATION AGE 14-17 (IN THOUSANDS)	ENROLLMENT IN SECONDARY SCHOOLS (IN THOUSANDS)			% AGE GROUP ENROLLED		
		Total	*Public*	*Non-public*	*Total*	*Public*	*Non-public*
1889-90	5,354	360	203	157	6 7	3.8	2 9
1899-1900	6,152	699	519	180	11.4	8.4	2.9
1909-10	7,220	1,115	915	200	15.4	12.7	2.8
1919-20	7,735	2,500	2,200	300	32.3	23 9	3.9
1929-30	9,341	4,804	4,399	405	51 4	44	4.3
1939-40	9,720	7,123	6,601	522	73.3	60.	5.4
1949-50	8,404	6,427	5,707	720	76.5	64.	8.6
1954 55	9,162	7,279			79 4		
1960 †	11,570	9,256	8,238	1,018	77	71.	8 8
1966 †	14,397	11,517	10,247	1,270	80.	71.	8.8

* Based on. *Biennial Survey of Education 1948-50*, Chapter 1. Table 16, also *Survey 1950-52*, Chapter 1, Tables 3 and 11, U S Government Printing Office, Washington, D. C.
† All figures for 1960 and 1966 are estimates



courses. Despite the introduction of general science and biology, the percentage of high school students enrolled in science at any one time has shifted from 84 per cent in 1900 to 54 per cent in 1949.[6] Such figures are often cited as evidence that in the "good old days" things were far better. Note, however, that the percentage of the *total* high-school age group enrolled in science shifted dramatically from a mere 7 per cent in 1900 to 37 per cent in 1955 (Table 21-2). Science instruction is now reaching a far larger proportion of the children than ever before in history. Furthermore, the social climate is such that we can expect this proportion to continue to increase. Certainly, we must be seriously concerned about who teaches these science classes and both the intent and the content of the instruction.

The importance of able science teachers

In the New York *Times*, January 9, 1955, Dr. Henry Chauncey, Director of the Educational Testing Service, was quoted as saying that "the manpower resources we fail to develop may cost us our survival." As every reader knows, the urgency of this observation stemmed principally from the need for additional military research and development. Financed at several billion dollars a year in pre-earth satellite times, the governmental budget for scientific research on military problems will increase and stay high for years.

Likewise, the pressures arising from a booming population, booming industrial production, and the impact of science and technology on life and living will continue to require more individuals working within science and technology. Within the general economy the need for people with technical skills, as well as for creative scientists, will continue to rise, since the nation's economy is highly industrialized and will become more so. In war or peace scientists have become a national resource. Science teachers, too, because they play a critical role in the early encouragement and self-identification of potential scientists, are a national resource.

We have noted, in this chapter and earlier, the key role of the teacher in developing future scientists. While we are deeply concerned about the supply of potential scientists, no teacher can disregard his responsibilities to the great majority who are indirect consumers of science and technology. As we have stressed, the attitudes as well as the knowledge of these millions are a teacher's major responsibility. Even now, close to half the children do not graduate from secondary school.[7] Their principal opportunity to become aware of science as something other than magic, or glamour, or bigger weapons comes within the secondary school, within the years of the early matching of individual gifts with opportunities. All our scientists-to-be are in the secondary schools. There is where the continuing shortage is to be met—by science teachers.

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[6] The percentage figure for 1890 in Table 21-1 is too low, but complete statistics of enrollments in 1890 appear to be nonexistent.

[7] Dael Wolfle, *America's Resources of Professional Manpower*, Harper, N.Y., 1954.

1934		1949		1955		1965		
No.	%	*No.*	%	*No.*	%	*No.*	%	
								Course
789	18	1,122	21	1,355 †	21 †	2,200		*General science*
657	15	996	18	1,294	20	2,100		*Biology*
41	1	8	0.1					*Botany*
82	2	54	1					*Physiology*
27	1	5	0.1					*Zoology*
77	2	21	0.4			200		*Earth science*
340	8	412	8	483	7	1,000		*Chemistry*
283	6	291	5	303	5	700		*Physics*
								Totals
2,305	52	2,909	54	3,435	53	6,200		*Science enrollment*
4,497		5,399		6,453		10,200		*HS enrollment*
9,500		8,300		9,162		14,400		*Population, age 14-17*
	24.3		35.0		36.5		43	*% age group enrolled in science*

The present demand for teachers

> The great cost of high schools of science is by no means appreciated. The necessity of having men of distinction in special investigations, and for having a great many special teachers, and for having ample means of experiment and illustration—all this is very imperfectly understood. The readiness with which men of truly scientific attainments are caught up to aid in the construction of public works, the development of mines, the exploration of new territory, the administration of great industrial establishments, and numerous other services, renders it difficult to obtain them as instructors of youth on the meagre allowances commonly bestowed for educational services.

This was not said yesterday, but in 1872 by President Daniel C. Gilman of Johns Hopkins University. Yet it is equally apt today.

To develop scientific personnel and citizens who will live in a scientific economy, the "quality" as well as the quantity of our science teachers is crucial. These effective science teachers are in short supply. Yet they are the ones who have the knowledge, attitudes, and skills to develop the potentialities of all our students to their utmost. Most teachers are persons who would be competent in industrial or government employment, but prefer to teach. Reports from many industries who have employed such science teachers in the summer support this conclusion.[5]

[5] *Teachers in Industry, Report of School-Industry Science Program for the Summer of 1956*, Sept. 1956, and *School-Industry Science Program, Summer 1956, First Status Report*, Oct. 1956, pamphlets, Hughes Aircraft Company, Culver City, Cal.
J. Ned Bryan and Edwin H. Cooper, *Science Teachers in Industry*, National Science Teachers Association, 1201 16th St., N.W., Washington 6, D. C.

TABLE 21-2 *Science enrollments in public secondary schools 1890 to 1965* *

	1890		1900		1910		1922	
	No (thousands)	% HS enrollment	No.	%	No.	%	No.	%
Course								
General science							394	18
Biology					7.9	1	189	9
Botany	‡				116	13	82	4
Physiology	‡		142	27	113	12	109	5
Zoology	‡				51	6	33	2
Earth science	‡		155	30	155	17	97	5
Chemistry	20.5	10	40	8	51	7	159	7
Physics	46	23	99	19	108	15	192	9
Totals								
Science enrollment	66.5 §	33	436	84	602	66	1,255	59
HS enrollment	203		519		915		2,155	
Population, age 14 17	5,354		6,152		7,220		8,000	
% age group enrolled in science	1.2+ §			7.1		8.9		13.7

* Based on: Office of Education, *Biennial Survey 1948 49*, Chapter 5, Table 7, U. S. Government Printing Office, Washington, D. C., 1953, and K. E. Brown, *Offerings and Enrollments in Science and Mathematics in Public High Schools, 1954-55*, U. S. Government Printing Office, Washington, D. C., 1956, plus personal communications

† Assumed on basis of 1949 data

‡ No enrollment figures available for these courses, known to have been commonly offered.

§ Incomplete

Percent of age group 14–17 enrolled in science (public schools)

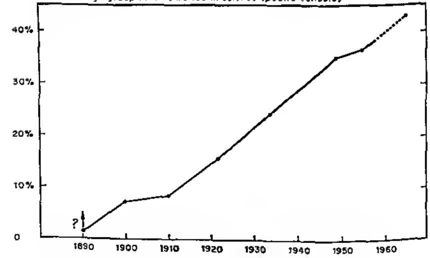
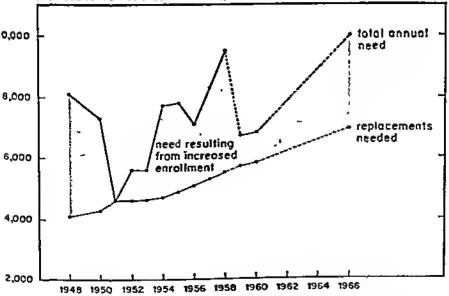


TABLE 21-3 ***Needed numbers of high school teachers and science teachers, projected to 1960 ****

	Number of high school teachers	*Number of science teachers (full and part time)*	*New science teachers for replacement*	*New science teachers for increased enrollment*	*Total number of new science teachers needed*
1945-46	289,495	58,000	—	—	—
1947-48	305,739	62,000	4,100	4,000	8,100
1949 50	314,093	65,000	4,300	3 000	7,300
1950 51	325,143	65,000	4,600	0	4,600
1951-52	329,173	66,000	4,600	1,000	5,600
1952 53	334,983	67,000	4,609	1,000	5,600
1953 54	351,000	70,000	4,700	3,000	7,700
1954-55	366,000	73,000	4,900	3,000	7,900
1955-56	377,000	75,000	5,100	2,000	7,100
1956-57	389,000	78,000	5,300	3,000	8,300
1957-58	411,000	82,000	5,500	4,000	9,500
1958-59	417,000	83,000	5,700	1,000	6,700
1959-60	419,000	84,000	5,800	1,000	6,800

* From *Critical Years Ahead in Science Teaching*, Report of Conference on Nation-wide Problems of Science Teaching in the Secondary Schools. Harvard U., Cambridge, 1953 Total need for high school teachers rounded off from Table III in "Teacher Forecast for the Public Schools," N.E.A., Research Division, *Journal of Teacher Education, 4*, 53, 1953.

The need for new science teachers (public schools)



would profit from the knowledge. Different teachers could readily become special resource personnel for various areas of new knowledge (see p. 522).

After a careful appraisal of enrollments and numbers of classes, Pella answered the question: "Are we using full-time science teachers wherever possible?" with an emphatic no. He concluded that "only 50 per cent of the possible full-time science teachers are presently employed." This result is similar to that encountered in many other statewide and nationwide studies. While the decisions in teacher utilization are basically administrative and occur in many separate schools, teachers, individually and collectively through professional groups, can do much to encourage wiser utilization of the teachers available.

The limitations resulting from the use of part time teachers in science are clear. Mostly they have meager command of scientific information and equipmental skills, but even more serious is their lack of interest in science. When the teacher lacks interest in science, the students cannot be expected to become excited or to have opportunities to practice sciencing in the classroom. Uninformed and insecure teachers cling tightly to their textbooks and reduce the class sessions to "talk and chalk."

Realistically, in all schools the number of science classes is unlikely to equal the full-time teaching load of an integral number of teachers; some part-time science teachers are inevitable. They need assistance in acquiring information, knowledge of resources, self-confidence, manual skills, and a "feel for science," expressed through teaching methods Likewise, the beginning teacher, no matter how well "prepared" for his task, needs continual advice and direction. We see then that constructive, sympathetic assistance or supervision is seriously needed now. In the years ahead, when many others even less well qualified will be in science classrooms, the need for help on the job will be greater. For the sake of the future adults, who have only one chance in their schooling, we hope that individual teachers, local school systems, and professional groups of teachers will act to provide the best assistance available.

Replacement. Unfortunately there are no accurate figures available on the number of new science teachers entering the schools each year. However, some fairly close estimates of the supply can be made from indirect figures. In 1955 there were 51,418 college graduates who were prepared to teach in high school.[11] These individuals took, in all the colleges of the country, whatever pattern of courses were required for certification in the state where they were to teach. While the certification requirements differ considerably between states, we may count these people as potential new teachers. Of this number 1,690 were prepared to teach general science, 1,371 biology, 602 chemistry, and 219 physics. All together there were 3,912 college graduates available as new science teachers. This is a drop of 57 per cent from the GI-boom year 1950 when 9,096 were prepared to teach science. (A similar drop of 51 per cent occurred in mathematics from the 4,610 in 1950 to 2,250 in 1955.) Yet we have seen (Table 21-3) that about 7,000 new science teachers are needed each year.

[11] National Education Association, Research Division, "The 1955 Teacher Supply and Demand Report," *Teacher Education*, Vol 6, No 3, 1955.

one additional subject, 202 taught two, and 42 taught three or more other subjects. The distribution of teachers between full time in *one* science, full-time in science, and part time in science is shown in Table 21-4.

This pattern of teacher utilization, confirming many similar reports from elsewhere throughout the country, is a crushing blow to those who would have future science teachers "highly specialized" in one science. Only the few larger schools can supply enough pupils to involve a science teacher all day within a *single science*. The blunt facts are that half the secondary schools in the country enroll less than 200 pupils per school, while half the pupils attend schools whose total enrollment is 100 or less. Science teachers in such schools must be able to provide competent instruction in most of the science areas and also in mathematics (not to mention physical education).

Certification laws, differing widely between states and usually rather vague, are little protection to the employed teacher or his students. Classes have to be taught by the employed staff, irrespective of the preferences or training of the staff. Any prospective science teacher will see for himself the necessity of a firm introduction to all the major fields of science and of mathematics, beyond which some specialization is desirable. In college the more basic courses in *each* area should be selected, these are the courses which are difficult to "work up" or read on your own.

No prospective teacher can learn in college all that he would like to know or need to know as an effective teacher. Continual reading according to a planned program, attendance at teachers' meetings, enrollment in correspondence, extension, and summer courses are means by which additional knowledge can be obtained. Many special opportunities for summer study are being provided with stipends through industries and the federal government. These will never be enough for all who want or need them, but they are helpful. We can visualize some of those who have had such special opportunities presenting repeat performances in their local communities for the benefit of others who

TABLE 21-4 *Distribution of classes of science teachers in Wisconsin, 1956* *

	General science		*Biology*		*Chemistry*		*Physics*	
	No.	*%*	*No*	*%*	*No*	*%*	*No.*	*%*
Teachers	476		514		341		316	
Full-time one science	33	6.9	88	17.1	32	9.4	16	5.1
Full time in science	112	23.4	99	19.2	139	31.4	90	28.5
Part-time science	331 †	69.7	327 ‡	63.7	202 §	59.2	210 ‖	66.4

* M. O. Pella, *op. cit.*
† Mathematics 113, physical education 101.
‡ Physical education 114, social studies 77, mathematics 67.
§ Mathematics 98, physical education 47.
‖ Mathematics 129, physical education 36.

Section Five

TOOLS FOR THE SCIENCE TEACHER

The term "tools" will have different meaning to different people; some teachers will think of tools in this sense using the microscope, using dissecting instruments, building a microprojector, devising an ammeter.

These are tools in a very special sense; they are dealt with in the accompanying volumes, whose tables of contents are to be found on pp. xx and xxi of this book. In these volumes there are several thousand special procedures and "tools" useful in the biological and physical sciences.

We think of tools in a more general sense, we have already discussed certain "tools" in prior sections. For instance the art of questioning (Chapter 4), lesson planning (Chapter 7), planning a unit (Chapter 17), planning with students (Chapter 4), the lecture (Chapters 7 and 13), constructing tests (Chapter 20), using readings (Chapter 2), planning a course (Chapters 10 to 18), the laboratory (Chapter 7).

To elaborate one instance, the use of the laboratory has been discussed and developed in different facets in Section I, in relation to ways of the scientist; in Section II, in relation to lesson planning; in Section III, in relation to the controversy between the lecture-demonstration and laboratory approach; in Section IV, in relation to "practical examinations." In the present section we deal with the laboratory in a very special and limited sense; we offer useful recommendations on the organization of a laboratory squad, facilities, and the like, without reference to teaching method. We do the same thing for the other tools; we deal with eighteen of them out of the myriad possible.

Like all teachers, we should like to improve our teaching; and further, since we have taken on the task of writing this book, perhaps we can, through you, be of service to other teachers. If you have a favorite and respected tool or procedure or source which you would like to share with others, will you send it to us? We shall, in a revision of this book, publish your tool or procedure with full credit to you. Or better yet, why not develop your teaching device for publication in the various journals we list on p. 518?

To build a profession of teaching, we need to build a respectable literature of tried and tested tools, devices, procedures, as well as a theory and method.

Our difficulties are increased by the fact that only about half of the potential new science teachers enter schools as teachers. Contemplation of these stubborn facts arouses gnawing anxieties about the place of science in our schools for the next decades

The future need

The magnitude of future needs for science teachers was explored at the Harvard Conference in 1953.[12] A committee headed by Henry Shannon, Supervisor of Science for North Carolina, prepared the material shown in the illustration accompanying Table 21 3. Experts in teacher recruitment checked the data and were in agreement on the results, which led to these conclusions:

1 By 1966 the total number of full- and part-time science teachers will approximate 100,000, an increase of some 35,000 over the 65,000 in 1955.

2 Each and every year until 1966 the need for new science teachers will exceed 7,000 and will approach 10,000 per year in the interval 1960 65.

3. Between 1955 and 1965 a total of at least 100,000 competent new science teachers will be needed.

4. The annual supply of potential science teachers is less than 5,000, of whom only about half actually begin teaching.

5. A serious shortage of science teachers is growing and will continue into the next decade or longer.

In view of these facts, the committee recommended that:

1. Local and state school administrators make careful and realistic estimates of their future demands for science teachers ten years ahead.

2. The National Education Association or the U. S. Office of Education gather, summarize, and publicize these needs.

3. Particular attention be given to the smaller schools, usually rural, from which teachers are often recruited for large cities.

4. Liberal arts and teachers colleges concerned about the quality of instruction in secondary schools immediately begin, in cooperation with professional scientific societies and associations, vigorous recruitment campaigns for secondary school teacher candidates, especially in science and in mathematics.

5. High school teachers deliberately work to encourage pupils to consider science teaching as a vocation.

6. School administrators concentrate responsibility for science teaching among a minimum number of qualified teachers.

7. Proposed curricular changes in science be carefully examined in terms of the number and ability of teachers required.

The responsibilities of the science teacher are great, especially great in these times. As with any other creative area, a lifetime of practice, contemplation, study, and self criticism leads to excellence. Teaching, especially science teaching, remains a personal invention.

[12] Fletcher Watson, Paul Brandwein, and Sidney Rosen, eds, *Critical Years Ahead in Science Teaching*, Harvard U., Cambridge, 1953, pamphlet.

In the interim between these questions students watched and took notes. The next day they went to the laboratory, and prepared oxygen according to the procedure they had watched. They then spent the rest of the double-lab period testing the properties of oxygen by procedures they had read about in their text and in a supplementary chemistry text.

A demonstration, in short, may be considered a *group experiment* in which selected members actually do the experiment, while all observe carefully and suggest procedures, devices, controls, and safeguards. All students take notes; all are expected to use, in future work, the knowledge gained.

The demonstration is not, of course, a substitute for the laboratory (see Chapters 7 and 13); it is but an additional tool of the teacher.

The following references offer useful suggestions for demonstrations.

SELECTED BOOKS

Crouse, W. H., *Understanding Science*, N. Y.: Whittlesey House, 1948.

Freeman, M., and I. Freeman, *Invitation to Experiment*, N. Y.: Dutton, 1940.

Joseph, A., E. Morholt, and P. F. Brandwein, *Teaching High School Science: A Sourcebook for the Physical Sciences*, N. Y.: Harcourt, Brace, 1959.

Lord, Eugene H., *Experimenting at Home with Wonders of Science*, N. Y.: D. Appleton-Century, 1942.

Lunt, J. R., *Electricity for Everyone*, N. Y.: Macmillan, 1943.

Lynde, C. J., *Science Experiences with Home Equipment, Science Experiences with Inexpensive Equipment; Science Experiences with Ten-Cent Store Equipment*, Scranton, Pa.: International Textbook Co., 1937, 1939, 1941.

Miller, David F., and Glenn W. Blaydes, *Methods and Materials for Teaching Biological Sciences*, N. Y.: McGraw-Hill, 1938.

Morgan, A. P., *Things a Boy Can Do with Chemistry*, N. Y.: D. Appleton Century, 1940.

Morholt, E., P. F. Brandwein, and A. Joseph, *Teaching High School Science: A Sourcebook for the Biological Sciences*, N. Y.: Harcourt, Brace, 1958.

Richardson, J. S., and G. P. Cahoon, *Methods and Materials for Teaching General and Physical Science*, N. Y.: McGraw-Hill, 1951.

Schneider, H., and N. Schneider, *Now Try This*, N. Y.: William R. Scott, 1948.

Simmons, M. P., *The Young Scientist*, N. Y.: Exposition Press, 1951.

Sutton, R., *Demonstration Experiments in Physics*, N. Y.: McGraw-Hill, 1938.

Swezey, Kenneth M., *After dinner Science*, N. Y.: Whittlesey House, 1948.

SELECTED PAMPHLETS

Association for Childhood Education, *Uses for Waste Materials*, Washington, D. C., 1951.

Blough, Glenn O., and P. E. Blackwood, *Teaching Elementary Science*, Washington, D. C.: U. S. Government Printing Office, 1948.

——, *Science Teaching in Rural and Small Town Schools*, Washington, D. C.: U. S. Government Printing Office, 1949.

Bruce, Guy V., *Experiments with Water, Air; Fuels; Heat; Magnetism and Electricity; Sound; Light;* 7 vols., Washington, D. C.: National Science Teachers Association, n.d.

Davis, Hubert J., *Some Handy Recipes for Science Work*, Mississippi: State College, Department of Adult Education, 1952.

Instructor Series of Illustrated Units, Dansville, N. Y.: F. A. Owen Publishing Co.

The demonstration

There are times when nothing but the demonstration will do, for example, when the teacher wishes:

To begin a lesson and demonstrate a phenomenon at variance with ordinary experience (e.g., a balloon sticking to the chalk-board, by electrostatic attraction).

To end a lesson leading to an extension of work at home (e.g., just a few minutes before the bell is to ring ending the lesson, he begins testing foods with litmus—oranges, lemons, etc.—the bell rings and he wonders aloud who would finish this at home and report to the class).

To develop a point during the lesson (e.g., students are discussing the difference between a single animal cell and a single-celled animal; at a suitable point the teacher switches on a bioscope or microprojector or film to show a paramecium and a cheek cell).

To highlight safety procedures in the laboratory (e.g., the first time students work with glass, the instructor needs to demonstrate how to insert glass tubing into a rubber stopper, how to bend glass, etc.).

To demonstrate processes generally too dangerous or too complex for students to handle (e.g., the Thermit process, the reduction of CuO, the dissection of an embryo pig, the first experience with circuitry in an oscillator).

To demonstrate additional aspects of laboratory work (e.g., it may not be desirable to have students do all types of preparations of, say, oxygen; one or more procedures might be demonstrated).

For whatever purpose the demonstration is used, its major function is to present evidence for a concept by doing, seeing, testing.

Who does the demonstration? The class; every student participates, in one way or another. The demonstration is part of the lesson; as such, it would be wasteful to lecture as it is being done. For instance, one teacher presented the routine preparation of oxygen in a general science class as follows:

1. Students set up the apparatus (they had read beforehand).
2. The teacher asked these questions:
   a. What substances are we to use? (The student who replied added the materials.)
   b. What is the equation for the reaction? (A student wrote it on the board.)
   c. How shall we proceed? (The students told the teacher, who added appropriate cautions on safety procedures.)
   d. How shall we collect the gas?

The film, with directory of distributors

We assume that you have the catalogues of educational film producers, most of whom are listed on p 481. Certainly your school library has the comprehensive *Educational Film Guide*, with regular supplements.[1]

Even a most casual examination of the catalogues or the compendium shows a rich variety of films, both sound and silent But it is the *use* of these films with which we are concerned. (Analysis of kinds of equipment we leave to texts on the subject and to the teacher, who knows his needs. In purchasing equipment we follow two simple rules: (1) we examine the equipment and use, as a base for comparison, demonstrations by salesmen who explain the merits of their product; (2) we use the resources of the Department of Audio-Visual Aids of the National Education Association, or other expert (see p. 481).

What are the uses of films? Again we repair to classroom observations.

As introduction to a topic: For instance, one effective way to introduce and capture interest in the topic of classification is to show a film of a variety of interesting plants and animals Or in stimulating interest in metallurgy, show an industrial film, possibly on the winning of a metal. There are many such films available.

We think it a mistake, however, to use the film constantly to introduce a topic; in teaching, as in life, variety of approach retains interest. For instance, we should not use a film to introduce a topic in which there is already great interest, such as satellites.

As a review of a topic: For instance, there are many films on light and sound which may serve as a review of the topic.

As a vicarious field trip: One cannot always go on a field trip to a farm or a laboratory or an industry; one can use a film instead. For instance, the class can visit a beehive (unless you want to keep one) via one of the many films available. So a class by means of a film can go on a field trip to see a farm harvest, an operation in a hospital, a cancer laboratory, erosion and its prevention, a Bessemer furnace, the manufacture of plastics, the mining of sulfur, a cyclotron—almost any kind of field trip you would want to devise.

Of course, a film does not take the place of a field trip. It is a vicarious experience, like the filmstrip, model, or chart, a next best way of getting experience and evidence.

[1] H. W. Wilson Co., 950 University Ave, New York 52, N. Y.

The chalk-board

The somewhat derogatory word "chalk-talk" has its purposes; unfortunately, it casts aspersions on chalk, which is one of the most useful "tools" of the teacher. Its unfortunate connotation, in science at least, arises from the fact that very often the chalk board is used only as an aid to the lecture and as a substitute for the experiment or the demonstration, as a substitute for seeing or doing.

Naturally, the teacher who has adapted the lecture to his own personality will use the chalk board as skillfully as he uses his personality and his language. When he has finished his lecture, students will clearly see on the board the evidence, argument, and conclusion of the lesson. But use of the chalk-board is not restricted to the lecturer. Teacher and students, no matter what the pattern of the lesson is, can make good use of the chalk-board.

As an aid in demonstration: Six students breathed on the board through their mouths, the class saw six spots of moisture appear and then evaporate. (Other similar devices are to be found in the accompanying volumes, *A Sourcebook for the Biological Sciences* and *A Sourcebook for the Physical Sciences.*)

As an aid in illustration: One teacher drew diagrams of many different protozoa as an aid to identification for the first microscope lesson.

As directions in aiding an experiment: A teacher drew wiring diagrams in color to assist his students in their *first* attempt to develop circuits.

As an aid to discussion: As points are made, students write their conclusions on the board for all to see and evaluate. Written statements are more easily analyzed than ones made orally.

As an aid to a report: As a student made a report he listed his major points, and the most difficult (technical) words he used.

As an aid to projections: One teacher we know projects his slides directly on the chalk-board. He then outlines in chalk the object projected, emphasizing major points or structures. When the projection is switched off, there, on the board, appears whatever the teacher wished to emphasize.

As a reminder: One teacher had a permanent sector of the board titled "A Reminder." There, schedules of visiting lecturers, field trips, demonstrations in the assembly, schedules of tests, or required reading were posted. No student could say he didn't know about them.

To emphasize and reinforce: And, of course, the skillful teacher uses the chalk-board to emphasize a point made by a student or the teacher himself.

We have found that it is a most useful procedure to develop the topic in which the film is used as we have described for the filmstrip (a "tool" section immediately following this one). Except that the film is used where motion lends meaning to what is being studied, the technique of its use is similar to that of other visualization.

The film can be controlled; it can be stopped during its showing at suitable points for discussion or for a class demonstration or experiment. It does not substitute for the teacher because the teacher uses the film as part of his design, as part of his plan for producing changes in behavior, for improving the skills, knowledges, and attitudes of the students in his care.

Films, like TV, can be used by the teacher; but since teaching is not to be equated with telling and showing, the teacher in the film is not the same as the teacher in the classroom. The film is but one more tool in the arsenal of the competent teacher.

Directory of distributors of films

Below is a list of industrial concerns that have films and issue catalogues for distribution, and commercial film distributors with addresses of their central offices. A more extensive list is presented in the accompanying volume, *A Sourcebook for the Biological Sciences* You will also want to consider lists prepared by your State Department of Education and other state and federal departments. See, in particular, U. S. Governmental Film Catalogue No 3434, U. S. Office of Education Bulletin No. 21, also Bulletin No. 12, *A Directory of 3,300 16 mm Film Libraries,* 1956.[4]

Allis Chalmers Manufacturing Co., Advertising Dept., Milwaukee 1, Wis.
Almanac Films, Inc, 516 Fifth Ave, New York 18, N. Y.
American Can Co, 100 Park Ave, New York, N. Y.
American Cancer Soc., 47 Beaver St., New York 4, N Y.
American Film Registry, 24 E. 8 St, Chicago 5, Ill.
American Guernsey Cattle Club, 70 Main St., Peterborough, N H.
American Museum of Natural History, 79 St. and Central Park West, N. Y., N. Y.
American Potash Institute, 1102 16 St, N W, Washington, D. C.
Associated Bulb Growers of Holland, 29 Broadway, New York, N. Y.
Association Films, Inc., 347 Madison Ave., New York 17, N. Y.
Athena Films, Inc., 165 W 46 St., New York 19, N. Y.
Audio Productions, Inc, 630 Ninth Ave., New York 19, N Y
Australian News & Information Bureau, 636 Fifth Ave., New York 20, N. Y.
Bailey Films, Inc., 6509 De Longpre Ave., Hollywood 28, Cal.
Bausch & Lomb Optical Co., 635 St. Paul St., Rochester 2, N. Y.
Beet Sugar Development Foundation, P. O. Box 531, Fort Collins, Col.
Stanley Bowmar Co, 513 W. 166 St., New York 32, N. Y.
Brandon Films, Inc., 200 W. 57 St., New York 19, N. Y.
Bray Studios, 729 Seventh Ave, New York 19, N. Y.
Bureau of Communication Research, 13 E. 37 St, New York 16, N. Y.
J. I. Case & Co., Inc., Racine, Wis.

[4] U. S Government Printing Office, Washington, D C., 1951.

As an accessory experiment. Not all schools are fully equipped; not all classrooms have gas, electricity, and water for every student; not all experiments can be done with facility by everyone. For instance, to show that light exerts pressure requires complex equipment, to demonstrate that bacteria do divide under special conditions is difficult. At that time a film may serve. But if it is to be a substitute experiment, then it might as well be treated as one:

1. Before the film is shown, the experiment is planned by the class; that is, an experimental design is devised. This heightens interest as the class compares its own design with the film's, it also forms a base for criticism.

2. Only that part of the film which is concerned with the experiment is shown. For instance, part of one film on hormones [2] is given over to an experiment on the effect of parathyroid hormone; the rest of the film is not shown at this time. The selected portion may be shown again and again until the class has milked it dry of meaning.

As an accessory microscope or microprojector: There are some things which cannot be readily shown at the appropriate time through ordinary microscopes or microprojectors (bacteria or other cells dividing, sperm entering egg, etc.). There are films which record these processes.

Again, the technique is as in the accessory experiment—to use only that part of the film and to observe it again and again (by running it again and again). After all, the portions of the film concerned with the observation desired take up only two or three minutes. And these portions need to be studied much as the same sort of things would need to be studied using the microscope or microprojector.[3]

As a test: One teacher we knew told the class at the beginning of the term that he would use a film at the end of the term as a test of their knowledge. When the time came, he showed a sound film but cut off the sound track. The students were required to reconstruct the findings in the film. This technique is useful for films dealing with a specific experiment.

And, of course, as a full-period lesson: The film can be used successfully as a full lesson, but unfortunately the use of the film is often less than creative:

1. The film is put on, and the class watches. Discussion, if any, is carried on after the film. No notes are taken.

2. Too often the narration is above (or below) the level of certain students, or even of the whole class. The narration can be cut off and the teacher can substitute his own.

3. Too often the film "teaches," even preaches, conclusions not justified by the evidence presented in it. We consider the film as a means of presenting evidence; the conclusions should be reached by the students, through discussion and argument. Again, the teacher can turn off the sound and the music.

[2] Note that we do not mention specific films. we believe that mention of a film or text in a book of this sort might be interpreted as a recommendation. Selection of films, texts, facilities, etc., remains, like teaching methods, a personal choice.

[3] In the accompanying volume, *A Sourcebook for the Biological Sciences*, a description of a homemade microprojector, effective for most materials used in the high school, is given.

The filmstrip, with directory of distributors

We should begin by noting that there is probably available a filmstrip useful for every unit (or large organized field of learning) in your courses of study. We urge you to develop a library of catalogues, which usually have brief descriptions of the filmstrips, as part of your resource file (p. 525).

Generally speaking, the purpose of the filmstrip is to develop a sequential series of visualized ideas aimed at the building of concepts, although it may sometimes be used merely to furnish a tour (e.g., of an industry).

We have before us several filmstrips—one aimed at the concept of electromagnetism, another at the concept of scientific method, another at the concept of photosynthesis. All of them lend themselves to an approach which we have seen fine teachers use, and which results in widespread participation. This is but one way, of *course, of using a filmstrip:*

1. The preceding day the lesson is decided upon; it may be planned with students, or be a sequence the teacher has in mind, or be part of an assigned report a student will make, or be chosen for some other reason.

In any event, overnight the students read in the general area of the subject of the filmstrip. The teacher examines either the filmstrip or its guide. Most guides have a fully illustrated sequence of the strip, with all the captions.

2. Next day, the teacher (or a student on the laboratory squad, p. 501) puts the title frame on the screen (before the class period so that class time is not wasted). As soon as the lesson begins, the teacher (or student) snaps on the machine, and the title (e.g., "How Green Plants Make Food") is flashed on.

3. The teacher asks, "What do you expect to find in this filmstrip?" In the very brief discussion which follows, the attention of the class is focused and the mental activity of students stimulated. Even those who "know" how green plants make food have their expectancy stimulated.

4. As each frame is on the screen, the teacher discusses it with the class. Questions are asked by the teacher; students draw upon their experience; notes are taken; all the devices of good teaching are exercised.

5. At any appropriate point, the teacher (or a committee, or a student, if it is so planned) does a demonstration, for two reasons. First, the tempo of attention is altered; but second, and more important, not everything can be learned from the filmstrip—some things are learned better in other ways.

6. As each "eureka" (Chap. 6) develops, it is placed on the board.

Coronet Films, Coronet Building, Chicago 1, Ill.
William Cox Enterprises, 2900 S Sawtelle Blvd, Los Angeles 24, Cal
De Kalb Agricultural Assn, Educational Division, De Kalb, Ill
Denoyer Geppert Company, 5235 N Ravenswood Ave, Chicago 40, Ill.
Dow Chemical Co, Advertising Dept, Midland, Mich.
Edited Pictures System, Inc, 165 W 46 St, New York 19, N Y.
Encyclopaedia Britannica Films, Inc, 1150 Wilmette Ave., Wilmette, Ill.
Ethyl Corp, Chrysler Bldg, New York 17, N. Y.
General Electric Co Advertising & Sales Promotion Division, Schenectady, N. Y
General Motors, Dept of Public Relations, 3044 Grand Blvd., Detroit 2, Mich
Hawaii Press Bureau, 1040 National Press Bldg, Washington 4, D C.
Hy-Line Poultry Farms, 1206 Mulberry St, Des Moines 9, Iowa
Ideal Pictures Corp 58 E South Water St, Chicago 1, Ill.
Institute of Visual Training 40 E 49 St, New York 17, N. Y.
Institutional Cinema Service Inc, 165 W 46 St, New York, N. Y.
International Film Bureau Inc, 57 E Jackson Blvd, Chicago, Ill.
Iowa State University Bureau of Visual Instructions, Iowa City, Iowa
Kansas State College, Dept of Poultry Husbandry, Manhattan, Kan.
Knowledge Builders 625 Madison Ave, New York 22, N. Y.
Lederle Laboratories, Div of American Cyanamid Co, 30 Rockefeller Pl, N. Y. 20
Library Films Inc 25 W 45 St, New York 19, N. Y.
Metropolitan Life Insurance Co, 1 Madison Ave., New York 10, N. Y.
Milk Industry Foundation, Chrysler Bldg., New York 17, N. Y.
Modern Talking Picture Service, Inc, 45 Rockefeller Plaza, New York 20, N. Y.
National Audubon Society, 1130 Fifth Ave, New York, N. Y.
National Fertilizer Assn, 616 Investment Bldg, Washington 5, D. C.
National Film Board of Canada, 630 Fifth Ave, New York 20, N. Y.
National Garden Bureau, 407 S Dearborn St., Chicago, Ill.
National Tuberculosis Assn., 1790 Broadway, New York 19, N. Y.
N Y. *Times*, Office of Educational Activities, 229 W. 43 St, New York 36, N. Y.
North Carolina State College, Dept of Visual Aids, Raleigh, N. C.
Ohio State University, Dept of Photography, Columbus 10, Ohio
Samuel Orleans & Associates, Inc, 211 W. Cumberland Ave, Knoxville 15, Tenn
Skibo Productions, Inc, 165 W 46 St, New York 19, N. Y.
Society for Visual *Education, Inc.*, 1345 *W. Diversey Parkway, Chicago 14*, Ill
Sugar Information, Inc., Sugar Research Foundation, 52 Wall St, N. Y. 5, N. Y.
Swift & Co, Public Relations Dept, Union Stock Yards, Chicago 9, Ill.
Teaching Films Custodians, Inc, 25 W. 43 St, New York 18, N. Y.
U S. Dept. of Agriculture, Washington, D. C.
U. S. Public Health Service, Communicable Disease Center, Atlanta, Ga.
United World Films, Inc, 1445 Park Ave., New York 29, N Y.
University of California, University Extension, Visual Dept, 2272 Union St, Berkeley, Cal.
Visual Education Consultants, 2066 Helena St., Madison 4, Wis
Ward's Natural Science Establishment, 3000 East Ridge Road, Rochester 7, N Y.
West Coast Lumberman's Assn, 1410 Southwest Morrison St, Portland 5, Ore
Westinghouse Electric Corp, School Service, 306 Fourth Ave, P. O. Box 1017, Pittsburgh 30, Pa.
Wilner Films & Slides, P. O Box 231, Cathedral Station, New York 25, N. Y.
Wisconsin Alumni Research Foundation, P. O. Box 2059, Madison, Wis
Wistar Institute, 36 St. and Woodland Ave, Philadelphia, Pa.
Wool Bureau, Inc., 16 W. 46 St, New York 19, N. Y.
Young America Films, Inc, 18 E. 41 St., New York 17, N. Y
Zurich American Insurance Co, 135 La Salle St, Chicago 3, Ill.

Tools for the science teacher **5**

The library lesson

It cannot be taken for granted that students know how to use the library, especially in science. It is valuable to devise lessons which require the use of the library during class time. Naturally, these lessons are planned with the librarian, who then becomes the teacher.

For instance, the topic "Plant and Animal Breeding" might be developed into a library lesson in this manner:

1. The topic might be stated "How have we improved plants and animals?"

2. The class, under its chairman, divides itself into groups concerned with various aspects, e.g., "For Food," "For Work," "For Beauty," and so forth. Some may search out specific aspects, for instance, "Dogs," "Horses," "Apples," "Blueberries," "Honey-bees."

3. The class goes to the library, and if this is the first lesson, gets from the librarian a demonstration of the cataloging and storing devices used in the library, as they apply to science.

4. The class begins work during that period and each individual student completes his assignment after class.

5. Students then report to the class on what they have learned.

A library lesson is particularly useful in general science. If it is given once every month or every two months, whenever an appropriate topic is available, the students learn a valuable technique. Some topics we have found useful for a library lesson are:

Plant and Animal Breeding
The Lives of Scientists
The History of Atomic Energy
Science in Industry
Industrial Processes (steel-making, soap-making, paper manufacture, etc.)
The History of the Earth

7. When the filmstrip has been shown, each student is asked to write a brief summary. He may refer to his notes, to the board, and to his recall of past experience and reading.

8. Selected summaries are read in class and rated by the class (that is, after a summary is read the teacher will say, "John, what mark would you give this out of 10?" If John says "8," the teacher asks "Why?" The class can quickly decide on the grade). The teacher gives the student two grades—the one given by the class, and the teacher's own.

One teacher we know reviews in this way: After showing the filmstrip and discussing it as above, he flashes on a frame, with the caption masked with a card. He then asks the students to describe the frame.

In any event, whatever approach is used, effective teaching practice indicates that the filmstrip be *used in* a lesson, and *not substituted for* a lesson. A filmstrip properly used is a lesson using visualization to help the teacher alter the behavior of his students in a desirable way.

Using a filmstrip properly is an art, and, with the increase in the quality as well as the number of filmstrips, it is becoming an excellent one in the arsenal of teaching tools.

Directory of filmstrip distributors

Academy Films, Box 3088, Hollywood, Cal.
Encyclopaedia Britannica Films, Inc., may be obtained at the following offices:
- 101 Marietta St., Atlanta 3, Ga.
- 3745 Crabtree Road, Birmingham, Mich.
- 161 Massachusetts Ave., Boston 16, Mass.
- 1860 E. 85 St., Cleveland 6, Ohio
- 1414 Dragon St., Dallas 2, Tex.
- 5625 Hollywood Blvd., Hollywood, Cal.
- 7421 Park Ave., Minneapolis 23, Minn.
- 202 E. 44 St., New York 17, N. Y.
- 2129 N.E. Broadway, Portland 5, Ore.
- 1150 Wilmette Ave., Wilmette, Ill.

Filmstrip House, 25 Broad St., New York 4, N. Y.
Jam Handy Organization, 2821 East Grand Blvd., Detroit 11, Mich.
Life Magazine, Inc., Filmstrip Division, 9 Rockefeller Plaza, New York 20, N. Y.
New York *Times*, Office of Educational Activities, 229 W. 43 St., New York 36.
Photo Lab, Inc., 3825 Georgia Ave., N.W., Washington 11, D. C.
Popular Science Publishing Co., Audio-Visual Division, 353 Fourth Ave., New York 10, N. Y.
Society for Visual Education, Inc., 1345 W. Diversey Parkway, Chicago 14, Ill.
Sugar Information, Inc., 52 Wall St., New York 5, N. Y.
Universal Color Studios, P. O. Box 216, Gracie Square Station, New York 28, N. Y.
Visual Education Consultants, Inc., 2066 Helena St., Madison 4, Wis.
Young America Films, Inc., 18 E. 41 St., New York 17, N. Y.

scopes, first in relation to work directed by laboratory sheets, then in relation to an experiment they plan. They are given "practical examinations" (such as those described on page 402) in use of the tools and in identification of microorganisms, rocks, and so forth.

Opportunity to repeat some of the classic experiments in science. This has been called "looking over the shoulder of the scientist." For example, in dealing with Lavoisier's classic experiment in heating mercuric oxide, the class begins with an assignment on Lavoisier, his life and times; reports are given. Then the experiment may be done as a demonstration by a group of students or by the teacher, according to Lavoisier's description.[1] This may be followed by individual or group work with HgO in the laboratory, studying its properties, percentage composition, etc. Then the class extends this work by continuing with Lavoisier's experiments in burning.

(Students might, as a project, prepare such an investigation into the history of science a month in advance of its "trial" in class—Priestley's experiments, Winogradsky's experiments, for example.)

Opportunity to vary standard experiments along "original" lines. Students are constantly asking questions after doing the standard experiments. For instance, after testing the reaction of *Paramecium* to salt, they may ask, "May we try ink?" The reaction of *Paramecium* in shooting out trichocysts in reaction to ink is most edifying and may lead to further work. Standard experiments may be varied ad infinitum.

Opportunity to do an "original" experiment or project in the laboratory. This can be sustained over a semester, or over several years. We discuss the project on p. 498. There is, of course, the matter of room for these experiments. Facilities for experimentation of this kind are at best limited. But many of these projects can be, and have been, *carried out in the preparation room* (see Science Facilities, p. 506); in a corner of the laboratory, in the ordinary classroom (a table set up in one corner, perhaps), at home, in a college or university laboratory; in a museum

A note on workbooks

Rarely does a meeting of teachers go by without someone's attacking the workbook. The controversy between users of workbooks and laboratory manuals is likely to continue for some time. Neal[2] has summarized what to us are salient points in the "workbooks, yes; workbooks, no" controversy. He writes:

> Workbooks for use in connection with secondary school science textbooks have recently been discussed at greater length than space permits here. Those who argue for the present type of workbook usually hold that it should be possible to do better workbooks—publications which would offer inspirational thinking exercises on a

[1] See the Harvard Case Studies, described in Chapter 2, page 48 of this book.

[2] Nathan A. Neal, "Textbooks, Workbooks, and Laboratory Manuals in Science," *National Association of Secondary-School Principals Bulletin*, Jan. 1953, pp. 129-37.

The laboratory lesson, with a note on workbooks

The word "laboratory" has been endowed with a mystical connotation; it is as if it were a church where one went in supplication and came out always with the desired answer—the solution to the problem. Discussions of the place of the laboratory by teachers of science sometimes border on unreality:

> *If only* students could use the laboratory to solve problems, the ways of the scientist would be taught
>
> *If only* the "cookbook" experiment were eliminated, if only we did not use "workbooks," we should truly teach science.

Yet reflection will show that the laboratory experiment is only *one* way of the scientist; before he enters it and during his work there, he spends much time in *thinking, reading,* and *consulting* Furthermore, much of his work in the laboratory is routine, the design of an experiment is perhaps more a matter of thinking than of working with one's hands.

It would seem to us that a full laboratory experience in high school should include the following.

Opportunity to learn to plan sequential work. First there is a period of *acclimation*. Students begin with directed laboratory work. These directions may be developed in the teacher's own work sheets, or may be found in good workbooks; the purpose of this work is to give students the feel of the laboratory, to find out where equipment is, and the like. Most important, its purpose is to permit the instructor to note ways of work and to note particularly those students whose habits of work may result in accidents.

After this initial period of acclimation, students are given the topic of an experiment and the necessary equipment, and asked (as an assignment) to plan their own experiments; these are checked and approved. The students then proceed on their own. For instance, after the first week's work on simple machines in the physics laboratory students may plan their own experiment on the inclined plane.

After a few such experiences students are ready to try a longer experiment. For instance, in chemistry students may work on an "unknown" *requiring many periods of work.* In biology students may classify an "unknown" animal under the microscope, dissect an unusual specimen, or go so far as to determine the genetic make-up of a special stock of *Drosophila*.

Opportunity to learn skills. Students learn to use burners, balances, micro-

scopes, first in relation to work directed by laboratory sheets, then in relation to an experiment they plan. They are given "practical examinations" (such as those described on page 402) in use of the tools and in identification of microorganisms, rocks, and so forth.

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variety of levels for pupils of differing abilities. These same proponents also say that cost and time limitations usually prevent the publication and use of the type of workbooks which it is claimed would be desirable. Arguments in favor of the usual read the book fill-in the blanks type of workbook are: *

1 It saves teacher time spent in writing exercises and other workbook materials on the blackboard for pupils to copy and use.

2 The preparation of workbooks—objective exercises, suggested activities, review questions—requires greater skill and more time than most teachers have for this phase of their work.

3 Workbooks assure study guidance for all pupils.

4. Workbooks assure some pupil time spent on daily homework.

5 Workbooks give practice in following printed instructions, an activity that is common in adult life.

6 Workbooks usually contain illustrations accompanied by sufficient exercises and questions to give the pupil real experience in interpreting illustrations or diagrams

7 Workbooks provide practice in reading for information rather than merely for pleasure, a skill which young people need to develop.

Those who argue † that present type workbooks are worse than none label them as hodgepodges of poorly selected, poorly organized, pedagogically unsound teaching devices. They observe that workbooks are often constructed in the cheapest possible manner with poor typography, low quality paper, cramped writing space, and are inconveniently sized. It is further argued that time devoted to routine workbook exercises, questions and tests could be better devoted to simple experiments, field trips, observations, and activities that are more stimulating and satisfying A publisher might answer that publication of the best possible workbooks would be as costly in time, editorial effort, and money as textbooks, and that the product would necessarily be priced outside any existing market for workbooks.

We find similar arguments applied to laboratory manuals for secondary school science. There are some who oppose published manuals because they tend to standardize pupil activity in the laboratory and discourage learning through individual experimentation. The critics often refer to even the best published laboratory manuals as "cookbooks" They argue that the only good laboratory manual is one made by the teacher on the job each year after he is acquainted with the interests and abilities of individual pupils. The *pro* arguments are to the effect that there would be much less laboratory work without printed manuals: that pupils with special abilities can design their own individual experiments. that the great majority need proved and printed procedures in order to achieve any results; that teacher time is saved, that expensive laboratory materials and equipment are conserved; that the printed laboratory manual need not be a "cookbook" in the hands of a skillful teacher ‡

* Jack Hudspeth, "Workbooks—? Yes," *The Science Teacher, 18,* 74, March 1951.
† Herbert S Zim, "Workbooks—? No," *The Science Teacher, 18,* 75, March 1951.
‡ Greta Oppe, 'Workbooks—Worktexts—Laboratory Manuals," *Metropolitan Detroit Science Review,* Vol. 12, No. 4, 1, 1952.

Preparing one's own workbook. We have seen teachers prepare their own mimeographed workbooks to meet particular situations, e g.:

1. A teacher of chemistry wished to introduce his laboratory work based on semi-micro techniques. (By the way, the evidence is by no means conclusive that skills in chemistry are learned better by semi-micro techniques, although

they are an interesting variation.) There are now several workbooks which use these techniques.

2. One teacher developed "case studies" in biology; these led to laboratory work.

3. One teacher modified certain college physics laboratory work for his high school class.

4. One teacher (dealing with science shy students—in this case slow learners) developed a full set of laboratory sheets in applied chemistry.

A deviation in the use of workbooks. One of the most interesting and fruitful interpretations of the workbook we observed was this: A teacher gave his class a "standard" workbook in chemistry and explained that this was their guide to the course. They would meet in the laboratory daily and each student could work as fast as he wished, but a deadline was set for all. He would need to supplement his work with reading in various texts, the examinations tested the subject matter of chemistry.

The teacher was in the laboratory for consultation, when he saw a general difficulty, or upon request, he would caution, ask questions, carry on a discussion, or do a demonstration. Apparently, a workbook can be used creatively.

1. The class finished the standard work in eight months; two months were left for doing "original work."

2. The gain in skills over a "regular" class was obvious even to the casual observer. The students were workmanlike and adult in their approach to the laboratory work; they had learned to plan.

3. On standard examinations this class scored higher than "standard" classes of similar pupils. For instance, in the state examination the mean score for this class was eight points above the others.

The quest for originality. In a heterogeneous group, there will be some students who will not be able to do even carefully directed workbook exercises. Some will manage well enough. And some will want to do more and learn more; a way of giving scope to such gifts in the laboratory may be indicated in this approach:

A student on the laboratory squad (p. 501) is assigned to each class. Students who have finished an exercise, or who, because of their skill or knowledge, have the teacher's permission to do so, may get equipment from this student laboratory assistant and proceed to "original" work (the plan is checked by the teacher, if only to avoid accident and possible injury).

Thus, any given laboratory may find students varying in the kind of work they do, from repetition to true originality.

Work in the laboratory, like work in the classroom, is an invention of the teacher and the students. But the teacher is responsible for the climate and the opportunities.

The field trip

Throughout this book we have mentioned various kinds of field trips; we assumed in doing this that the field trip is a necessary part of teaching science. The basic reason for trips is clear: to provide additional evidence and experience that cannot be had within the classroom.[1] Even apart from the main purpose of the trip, biological, astronomical, etc., there are many concomitants:

1. Students get to know their community, or its surroundings, better.
2. They get insight into vocational opportunities (e.g., a trip to a dam or bridge may inspire an engineer; a trip to a pond, a conservationist or biologist; a trip to a weather bureau, a meteorologist).
3. They collect materials: animals (frogs, harmless reptiles, small invertebrates); plants (ferns, mosses, fungi, seeds); rocks and minerals; building materials (insulating materials, stone, brick); and so on.
4. They may develop hobbies: photography, astronomy, hiking, making and displaying collections.
5. They have fun, and develop better relationships with the teacher and with each other.
6. They may develop a sense of beauty

Probably any teacher could add to this list of desirable concomitants to a field trip. It must be remembered that these things do not automatically occur; they must be planned for just as carefully as the subject-matter purpose of the trip is prepared for. The students can do much of this preplanning, and, we feel, should take on responsibility for finding appropriate solutions to questions which must be answered when a field trip is being considered—where, when, why, what, who, and how? If the trip is to be significant to them, they should share in the responsibility. This will relieve the teacher of some details and also will help keep the group under control and give purpose to the effort.

Although a field trip can yield so much if it is well conducted and prepared for, it is a difficult thing to carry out. A field trip takes more time than a class period; it disrupts administrative procedures; there is danger of accidents; and, above all, the field trip takes careful, even arduous, preparation.

A file of possible field trips with specific instructions about persons to contact for permission (address, telephone number), route to follow, transportation, fees, hours possible, meals available, housing (for overnight trips),

[1] See F. G. Watson, *Using Museums for General Science Classes*, Bulletin 6, Wesleyan University Press, Education Center, Columbus, Ohio, free.

rest rooms, etc., is exceedingly valuable. One such file for the school, or even the school system, is better than a separate file for each teacher; by pooling our knowledge and experience, we can eliminate much of the drudgery.

Preparation for the field trip. Almost any kind of field trip requires preparation like the following (plus careful planning of the subject of the trip):

1. Obtaining permissions: principal or superintendent, parents, landowner or director of museum, industry, etc.
2. Note to parents: purpose of trip, time of leaving and return, place, cost (if any), equipment and clothing recommended, kind of transportation.
3. Planning with assistant leaders: guides, managers, parents, student helpers, briefed as to age and interest level of group, goals of teacher.
4. Safety: first-aid kit checked (assorted bandages, roll of gauze, adhesive tape, scissors, antiseptic, naphtha soap, other items depending on nature of trip), rules understood by students, forethought given to danger points.
5. Equipment: notebooks and pencils, other equipment depending on nature of trip, if collecting trip, containers, newspaper, trowels, vasculums, knives, nets, guides and keys, field glasses, cameras, etc., classroom set up in advance to accommodate whatever may be brought back.
6. Transportation arranged and permission obtained.
7. Lunch: individual or group; preparing and clean-up committees.
8. Alternate program in case of rain or other cause of cancellation.
9. Follow-up: reports, discussion, conclusions, new activities.

One approach to a field trip to study plant life. There are many ways to study plants in the field: the teacher may conduct a guided tour; students may be taught the use of the key in the lesson before, and taken out to practice what they have learned; students may simply collect specimens on a field trip, and bring them back to the classroom to identify them. Or perhaps the following approach may be useful.

On a field trip to a pond area students began to ask, perhaps idly, "What kind of tree is that?" The teacher suggested that they identify it as follows:

1. Give each type of tree a number instead of a name.
2. Note the characteristics of each type of tree, particularly those which set it off from the others. (For instance, the lobed leaves, opposite branching, and winged fruits of the sugar maple were listed as identifying "Tree No. 1.")
3. Take a "practical examination" (this required them to associate the numbers with the sets of characteristics).

Students thus learned the characteristics of the different trees by numbers; they did not have the obstacle of learning scientific names at the beginning.

While the students were eating lunch after this activity, the teacher placed labels on the numbered trees, giving their common and scientific names. Somehow this procedure excited the students, so that they spent special effort in associating the name with the characteristics they had previously learned.

One approach to a field trip in astronomy. Two major types of astronomy field trips come to mind, one for field observations, the other to an observatory or planetarium. Let us explore a trip for observations.

When: probably best taken in the autumn when the evenings are still warm but the sun sets early. A moonless night, perhaps about seven p.m., when the sky is nearly as dark as it will be, would be the best time to arrive.

Where: any convenient place, relatively away from street lights and auto lights, with a fairly clear horizon (the local football field or a hilltop farm), as near at hand as practical; long drives take time and may result in "lost cars." Arrange in advance for permission to use the property chosen.

Transportation: on foot if possible. Possibly by school bus, otherwise by automobile. In any case, get signed permission slips from parents. Check drivers for liability insurance, as well as driving skill. Provide each driver with written instructions of route, including a map. Proceed in a convoy if possible.

Who: preferably all students in the class plus others who may be interested; parents, both as drivers, and because they may be interested (good "public relations"), amateurs who may bring telescopes and otherwise help with the group.

Why: to obtain firsthand answess to questions important to the students.

Special equipment: flashlights, star maps, warm clothes, telescopes (if available by loan or with owner), binoculars, one or two cameras for pictures of constellations and star trails (loaded with the "fastest" film, like Tri-X).

Possible observations: A special trip such as that indicated is not necessary for observation (projected) of the bright sun or the moon, which can be observed during the day from the school grounds. Possible observations:

1. Any bright planets: Venus, Mars, Jupiter, Saturn, Uranus. The last is greenish in color, but not readily found; it shows a disk only under quite high magnification. Take note of the color, angular diameter, surface markings, phase, crescent (if any), annual motion across sky, satellites.

2. Stars: Star patterns (omit the faint, inconspicuous ones), stability of patterns with time (zodiacal constellations named some 5,000 years ago). Rising and setting of star groups, circumpolar motion of Big Dipper and Cassiopeia. Set one camera with wide-open lens pointing toward polar zone and take one-hour time exposure. Also take short exposures of one minute of polar region and of other interesting star groups (Northern Cross in Cygnus, Lyra, Cassiopeia). Star colors (relation to surface temperature). Star brightnesses. Location of naked-eye variable stars (Algol, Mira, Delta Cephei). Note the band of the Milky Way. In October, the "summer Milky Way," including Cygnus, will be visible; note great split or rift in Milky Way and faintness of western side (due to interstellar dust and gas). With binoculars or telescope, observe faint stars not individually visible to the naked eye (mention Galileo's discovery of fainter stars). With the aid of a star map or list of interesting objects, locate and observe a double star, a star cluster, a gaseous nebula, and possibly a galaxy.

3. Possibly meteors (shooting stars) and auroral activity.

4. Questions and comments for further investigation in the classroom.

each paragraph, summarizing these thoughts in writing, and using the table of contents and index. We found that teaching reading of science this way reduced the time students needed to do their homework, and raised reading scores on an objective test (p 153). The method we described was particularly useful with the science shy, but also improved the reading of the science prone.

We have found it useful to give a lesson in which students use their texts in class every week or so. The occasion for this may be a lesson planned by the class (again we note that "the class" includes the teacher), or planned by the teacher who recognizes that students are not using the text fruitfully. Topics which seem suitable for this type of lesson are:

A first lesson on the periodic table.
A lesson on classification.
Plant and animal breeding.
Industrial applications of chemistry (metallurgy of iron, Haber process, uses of nitrogen compounds, uses of nonmetals, etc.).
The solar system.
Predicting weather (including weather maps).

In using the text in class we have observed several devices particularly useful for discovering the poor reader. If the teacher goes from desk to desk (assuming, of course, a permissive, nonthreatening atmosphere), students will admit their difficulties, which are often easily remedied. Perhaps a student doesn't realize that he can make use of the glossary or a dictionary; perhaps he doesn't realize that he should take notes of the major thoughts as he reads, perhaps he sticks at certain words and worries about them, instead of going on and looking them up later. By using the text in this way, of course, the teacher helps the students acquire more efficient study habits.

Toward the end of the lesson, time may be taken to have students read aloud their summaries, which may then be criticized.

In addition, if students have been taught to use the text properly, they can very easily review for a test; their summaries should be saved for this purpose.

To read ahead. By means of the test described in Chapter 20, students are stimulated to read ahead. If they do advance reading, even in order to raise their grades, at least they have done the reading. It is to be hoped, of course, that the teacher will make the work of the class so interesting that the students will want to read ahead even without the bonus of extra points.

The text in the laboratory. When a laboratory session is scheduled some teachers wheel in a library cart with some reference texts, some college texts, some industrial applications, and others such as *How To Do an Experiment*.[2] Better yet, have such books continuously at hand, and mention those of special pertinence to the laboratory work.

[2] P. Goldstein, Harcourt, Brace, N. Y., 1957.

Supplementing the text

It is impossible to find or write one text which fits the entire range of ability in a class. In reading ability alone, tests of more than 4,000 ninth-grade students showed scores of 4.5 (fourth grade) to college level. Even homogeneous classes will be heterogeneous for some ability which has bearing on the text they use. To help all students in the class learn as much as possible, diversified reading materials are essential. The following procedures have been helpful in overcoming the problem of varying ability:

1. All students are provided with one basic text chosen for general coverage, ability to interest students, and accuracy.

2. All students are provided with a second text appropriate to their abilities: the science prone with a college text perhaps, the science shy with an easier text, or pamphlets, or texts for slow readers.[3] The purpose in providing dual texts is obvious: to improve reading level, the student should have not only a text on his present reading level, but also at least one above it. If funds are not available to provide each child with a second text, a few copies may be made available and the students encouraged to use them.

3. Of course, a good library is needed to amplify any text. For useful suggestions for beginning a library, see the volumes accompanying this text, as well as part of The Professional Library, p. 516. Without a library a basic text can hardly be expected to meet the varied needs and interests of children.

One way of pointing students to the library is to have them do, as an assignment, the suggested activities at the end of the chapter of the text; these often indicate additional reading and can also lead to project work.

4. In addition to books in the library, encourage students to buy their own. A good number of excellent paperbacks are within the price range of most students; some of these are listed in The Professional Library.

5. In addition to supplementing the text with additional material, the teacher will find it necessary to supplement it with recent news. One of the excitements of science is the new developments and ideas, which can be emphasized to the students by attention to news reports. Have you tried a bulletin board titled "The Current Text"? On it students could post information about recent discoveries or articles from *Scientific American*, *Science News Letter*, and other magazines and newspapers. Or the teacher or students can write summaries of recent advances and mimeograph them.

We hope that the teacher will have at hand diversified text materials appropriate for his own use. Fortunately, the variety of texts available in the United States is immense. But the text, no matter how readable or thorough, is only one of the instruments used by the teacher to attain his purposes.

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[3] Such books are now available in general science and biology. In ninth-grade general science a book with a seventh-grade reading level is used in addition to the regular text. Also, some general science texts contain sections appropriate for slow readers. Pamphlets (even the General Electric "comic books") can be used as starters for the very slow readers.

Tools for the science teacher **10**

The report

Essentially, the report is a short lecture given by a student; if the reporter is not skillful, the report can be boring and confusing. If it is not carefully prepared in advance, it is not only boring, but also a waste of time. Hence it is important for the teacher to teach the technique of *student reporting*. The English teacher will probably be delighted to cooperate.

A few students are skillful in communicating information, but most are not. Yet all students need to learn the skill of oral communication of information; and communicating scientific information requires especial clarity.

One teacher we know used the following techniques in teaching reporting: First, he discussed with the class the problems of reporting skillfully. The students generally agreed that to give a report the reporter had to plan his report and give it in an interesting fashion. Of course, the classmates of the reporter would take notes because they were responsible for information in the report. The teacher discussed with the class the nature of lesson planning (as in Chapter 7). A report was planned under the following heads: (1) The beginning; (2) The middle; (3) The end.

The *beginning* was intended to gain the interest of the audience; the title of the report was woven into the brief beginning. The *middle* was the body of the report; here the information was given with illustrations (slides, filmstrips, demonstrations, models, charts). The *end* was a summary. All reports were open to questions by classmates, who were responsible for the information communicated, and the teacher, who could often help make a point clear.

The practice this teacher followed was that of giving the first report himself. He tried to demonstrate:

Reference to notes (without reading them).

Brevity (he limited himself to a stated time—five minutes at the most).

Simple illustration (he used the chalk-board for simple drawings, demonstrating, by the simplicity of his illustration, what most students could do).

Loudness and clarity of speech.

At the end of his report, the teacher again discussed with the class the features of the reporting technique.

During the term every student had an opportunity to give a report, and in that way gained confidence and skill. And every now and then the teacher again reported to the class to afford students an opportunity to discuss the reporting technique, and, in reappraising it, to improve their own method.

The project

The project *is meant to individualize instruction. It is clearly* an effort to equalize opportunities (once again, equal opportunity does not mean identical exposure) so that those who have special abilities have the opportunities to fulfill themselves. Every youngster is an individual and the best instruction is for the individual need; the project, whether individual or group, helps us do this.

The project approach was discussed in part in Chapters 3 and 9. But here we want to deal with it as a tool for the special care of the individual, gifted or not. In our experience, this is one of the best ways not only to stimulate interest in science, but to help young people grow and gain status.

Sponsors for project work. Project work takes the time of interested people. Who sponsors it?

1. Interested teachers who are willing to give time to students before, during, or after school hours.
2. Interested parents with special training—engineers, doctors, or technicians of all sorts.
3. Scientists in the local industries.
4. Scientists in the local university.
5. Scientists, or teachers, who advise students by correspondence. (One of our students corresponded with a scientist on the West Coast, and completed a project in a field in which we had little skill or information.)
6. Any responsible person, with time and ability.

In one city, three schools banded their facilities and sponsors.

Sources of project work. Since the project should have a bit of originality about it, many teachers feel they should not attempt the work unless they have special training. Of course, as one does project work, one develops skill in aiding youngsters break through the thin walls of their tiny sphere of the unknown—their project. There are many ways to get suggestions for projects; some of them are:

1. Your colleagues.
2. Readings in the *Scientific American, Science News Letter, The Science Teacher, The American Biology Teacher, The Quarterly Review of Biology, The Journal of Chemical Education, Physics Today, Science World, Popular Science,* and many others. Does your library get these journals?

3. In chemical, biological, physics abstracts are regular reports—abstracts of papers—by scientists. When students leaf through these they get ideas for projects. They may correspond with the scientist who is the author of the "project" report, the abstract of his research. We have found scientists in industry and in the university generally gracious in corresponding with students who ask reasonable questions.[1] In many instances this has helped a student decide for a career in science.

4. Future Scientists of America, Science Service (Westinghouse National Science Talent Search),[2] and other organizations have helpful publications, as listed on pp. 526-30.

Space for project work. Often projects are not done for lack of space. A corner in the laboratory, the demonstration table in the preparation room or in the classroom, a cellar in the house of one of the students, a table in a garage—anywhere where the facilities needed are present will do. In one community, the Parents' Club donated the funds for the equipment; in another community, the students worked in the fire house, in another, they worked in one of the town garages In still another community, the high school had excellent facilities, but the local college furnished additional facilities.

How does the teacher help a student do a project? Originally we had written a rather lengthy section, How To Do a Project. This was before Philip Goldstein's book, *How To Do an Experiment*,[3] became available. This book is so complete, so useful that we recommend it without reservation. A student who refers to it can begin a project, and with the aid (over the rough spots, such as purchasing equipment) and blessing of his teacher and other sponsors, complete his project or experiment.

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[1] In the name of good public relations, make clear to your students that they should not write asking for "*all* the information about turtles, comets, cyclotrons, etc."! Such letters cannot be answered either effectively or politely Specific questions based on thought and reading will produce helpful replies.

[2] Have you seen the publication of Science Clubs of America, Science Service, *Thousands of Science Projects*?

[3] Harcourt, Brace, N. Y., 1957.

Science clubs and science fairs

The science club

A science club is not a new idea The Royal Society of England was an early "club" for purposes of scholarship In a very small way, our science clubs are "royal societies" of their own, those who join these clubs are on the royal road to learning—doing more work, learning more, and willing to spend time to do so. A science club consists of a group of students so interested in science that they group themselves (to serve their interest, perhaps) beyond the regular class time, usually a teacher is the focus, even the reason, why the students have the interest they do.

In our experience, and from our talks with principals and departmental chairmen, clubs seem to center around an inspiring teacher; poor teachers do not have clubs Since participation in a science club is a free choice, students must have considerable freedom to operate their own club. A dominating or restricting sponsor will attract few club members. The clubs varied their activities from the general, such as "The Science Club" to the special, such as "The Geneticists" One school had fourteen science clubs. Another had one, with twelve divisions from the "Camera Group" to the "Fossil Hunters."

How is a club organized? What does a club activity involve?

Fortunately, a good deal of help is available; one of the best sources is the *Science Club Sponsor's Handbook.*[1]

The science fair

Science clubs often lead to science fairs, where students exhibit their work Some schools have their own fairs, other schools group to have city fairs; cities and towns group to have county fairs; county fairs group to have state fairs; state fairs group to have national science fairs.

How does one organize a science fair? How does one gain entry into existing fairs? What are the standards of a good exhibit? Here, again, a good deal of help is available. Information may be obtained from Science Service, from *A Manual for Science Fairs,*[2] and from the organizations listed and described in The Resource File, p. 525.

[1] Science Service, 1719 N St., N.W., Washington 6, D. C.

[2] Prepared by Educational Section, American Museum of Atomic Energy, P. O. Box 117, Oak Ridge, Tenn.

Student laboratory squads

All teachers of science have a heavy schedule; not only do they teach a normal number of classes (as do their colleagues in English), but also they need to prepare and repair equipment, and prepare for demonstrations and laboratories. Many of the routine chores necessary in preparing the next day's lesson can be accomplished through student assistance; that is, by organizing a student laboratory squad.

Some of the tasks a laboratory squad can take upon itself are offered below as examples:

1. Show films and filmstrips (where teachers call for such help).
2. Clean equipment (microscopes, balances).
3. Maintain animals (rats, frogs, fruit flies).
4. Prepare, catalogue, and store charts.
5. Check inventories of chemicals.
6. Collect materials necessary for study (frog's eggs, cocoons, seeds, rocks, discarded radio parts).
7. Build equipment of various kinds (germinating boxes, pinhole cameras).

Although no one plan can be tailored for all schools—for each school is more or less unique, with varying specializations and divisions of labor—the following flexible plan may serve as a pattern. The procedures suggested here apply to the larger schools where there may be several classrooms and one or more laboratory rooms for science, and so not all the suggestions will apply to the smaller schools. Yet every teacher will find some that can be adapted to his own situation.

An individual teacher may send out a call for volunteers. In a large department, a more cohesive organization can be evolved if all the teachers in it work together. Since students must work under a teacher's supervision, "working time" for students and teachers may be before school, after school, or better, during students' free periods throughout the day. The method used will depend on which blocks of time can be coordinated with the teacher's time allowance.

Filling orders. Under the guidance of a single teacher or a laboratory assistant,[1] students can be trained to prepare the materials teachers have

[1] Some large cities in New Jersey and New York employ trained laboratory assistants. These are people carefully trained in science who prepare the laboratories, maintain equipment, and help students carry on projects. They are extremely valuable.

TEACHER	DAY
CLASS	PERIOD
10 large test tubes	rubber bands
test tube rack	10 corks to fit test tubes
brom thymol blue	beaker
3 sprigs of elodea	straws
carbon paper	

requested for the day. One plan which works successfully in large schools is to have teachers list all the specific materials they want twenty-four hours in advance, perhaps on an order blank like the one shown above, and deposit the lists in a box reserved for them. Two students might be given the responsibility to read through these order slips and inform teachers of conflicts (two teachers want the same teaching materials) so that the teachers involved may either share materials or resolve their needs in some other fashion. Thus, where necessary, the teacher is given time to plan for other activities in advance of class.

Delivering supplies. Student laboratory assistants are trained to find the materials in the laboratory. This presupposes an orderly arrangement of the laboratory, with drawers, shelves, and cabinets clearly labeled to identify their contents. Small orders may be stacked on a tray; large orders involving glassware, chemicals, microscopes, and the like, may be stacked on a cart which can be wheeled to classrooms. Materials should be distributed to the classrooms and returned to the laboratory by students when there is no traffic in the corridors. *This is an imperative safety regulation.* (Other safety regulations are the same as those for all students in the laboratory;[2] in addition, dangerous chemicals, such as bottles of acids, and stacked Petri dishes, should be placed within a larger battery jar or box to avoid spilling or smashing in transit.)

Cleaning up. When materials are ready for return to the laboratory, they should be replaced immediately in their storage locations. Some teachers

[2] *For one set of safety instructions, see the companion volume, A Sourcebook for the Biological Sciences.*

find it convenient to store materials in boxes organized by unit or problem area. However, this often immobilizes pieces of equipment. Part of the laboratory squad should wash up glassware used the previous period, while other students on the squad distribute the materials to the classrooms for that period.

In smaller schools, the student assistants may be responsible for getting, from the storeroom, materials teachers list as required, so that they are immediately available either at each student's work table or in an assigned place in the room. They can also be given responsibility for cleaning up after the laboratory period or at a time convenient to both teacher and student.

In addition. Some students on the laboratory squad work well with their hands. Those with manipulative skills may be stimulated to devise wall racks for magazines or for glassware and storage racks for charts, among other laboratory needs. Students with artistic talent can prepare charts drawn on window shades or muslin sheeting, or drawings on glass slides for projection. Models can be made in clay or papier-mâche.[3]

During lulls in the laboratory work (dependent on the size of the squad), there may be time for those youngsters with deep interest in science to make explorations, to try out demonstrations, to perfect skill in the use of the microscope and other tools, and to read widely

A typist in the group can be given responsibility for sending requests for free materials, ordering films for the next term's use in the classrooms, and making neat labels for exhibits.

Although students vary in their abilities and are thereby assigned appropriate and specific responsibilities in the laboratory, it is important that there be mutual cooperation. Everyone should "pitch in" when needed. There should be a rotation in the routine chores, if only to maintain esprit de corps.

Continuity of the squad. Since time and training accompany the molding of a responsible squad so that it becomes a cooperatively functioning unit, there arises the problem of replacements. There is always some turnover from year to year. However, many students do continue to work on a laboratory squad until they are ready to graduate from high school. One solution to the problem is that an experienced laboratory worker, during his last term on the squad, may be able to assume responsibility for training a novice from a lower term, possibly a freshman. By this method a laboratory squad always has some experienced students in its ranks and thus, in a sense, is self maintaining in membership.

In return. The prestige and camaraderie afforded by membership on a laboratory squad which has high standards of work will draw youngsters of many talents and many motivations. Some youngsters may be interested mainly in the sociability developed; this, too, is healthy and a necessary aspect of adolescent life. A wise teacher can be firm yet kind in demanding fulfillment of responsibilities.

[3] See the accompanying volume, *A Sourcebook for the Biological Sciences.*

Those few youngsters who seem to lack any special talent or those who seem to "forget" responsibilities quickly, but who say they are interested in science (it may be no more than the fascination of sparkling glassware), can be assigned more mundane chores, such as dusting, straightening up, washing glassware, or assisting in taking inventory. They have expressed a desire to work on the squad, let them satisfy that desire. High grades in science should not be the criterion for selecting students for work on a squad. Furthermore, such assistance should not be counted towards grades, although the experience will show on tests and reports.

In many instances, the work on the laboratory squad gives young people an opportunity to develop interests which lead to a future vocation or avocation. Or they may develop friendships. Or they may develop a sense of service, of citizenship, of giving, if you will. This last, some teachers think, is the most important contribution of the laboratory squad to its members, and of its members to the school.

The bulletin board and the exhibit case

The bulletin board

Throughout the country, school bulletin boards are used as follows:

For notices. Notices of new books, articles in magazines and journals, scholarship examinations, fairs and exhibits, club meetings, and so forth.

Current events. A recent bulletin board exhibit had newspaper accounts of the latest earth satellite with photographs. In addition, students had developed their own short history of the development of rockets and satellites. There was also a section entitled "For Further Developments"

Problem of the week. Once a week a committee of students posted a problem in physics, in chemistry, in biology. Students were free to answer it. At the end of the week, the answer was posted for comparison.

Special bulletin boards. In one school, one wall in the laboratory was given over to a series of small bulletin boards, each designed for one club. Notices of meetings, topics for discussion, lists of members, and notices of visiting speakers were posted. In another school, with a weather station, one bulletin board called "The Weather Vane" was a popular stopping place for students, who compared forecasts of student weathermen with professional ones.

These are but a few examples of the use of bulletin boards as teaching tools. Frequent changes in the materials posted and attractive arrangements are essential. Interesting bulletin boards will attract attention, and extend science into the life of the school.

The exhibit case

The floor plans on p. 509 show exhibit cases. These cases are exceedingly useful for, among other things:

Exhibits of materials related to the topic at hand: examples of invertebrates (study of classification), minerals and rocks (study of geology), etc.

Exhibits of projects: individual or group.

Exhibits of books and printed materials: by librarian or teachers.

Exhibits of laboratory set-up for the day (if it is to be complex).

We have found that students like to set up exhibits. They introduce novelty and frequent change to attract attention. Learning is thus stimulated outside the classroom, and is reflected in work in the classroom as well.

Science facilities, with directory of suppliers

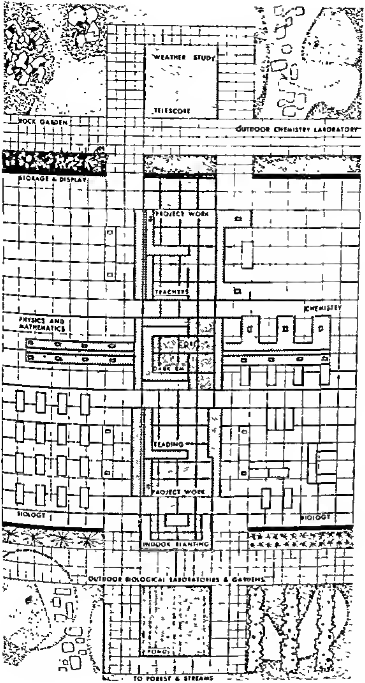
Sooner or later a teacher has the opportunity to help design a new laboratory, refurnish or modify the one he is working in, or even draw up plans for a whole new building including science classrooms and laboratories. Ideally a science room should fit a teacher's personal teaching invention. But since he is not the only teacher who will use the room, it must be so contrived as to meet the needs of all. Where can a teacher find help?

There is no dearth of help. But like teaching itself, the facilities for science teaching are personal inventions. Hence, one examines all the material available and makes a selection suited to the teacher, the school, the community, and above all the youngsters being taught. It is useful to visit different schools and seek the advice of their experts. Science equipment companies (see list on p. 514) will often furnish consultants. In addition, there are several very useful references:

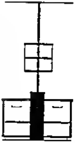
Hurd, Paul deH., *Science Facilities for the Modern High School*, Educational Administration Monograph No. 2, Stanford U. Press, Stanford, Cal., 1951.
Johnson, M. R. A., and H. A. Shannon, *Science Facilities for Today's High Schools*, Department of Public Instruction, North Carolina.
Johnson, P., *Science Facilities for Secondary Schools*, No. 17, Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., 1952.
School Facilities for Science Instruction, ed. by J. S. Richardson, National Science Teachers Association, 1201 16 St., N.W., Washington 6, D. C., 1954.

From *Science Facilities for Today's High Schools*, a brief but very useful guide, we reproduce a representative part, with illustrations.

> Plan A is a suggestion for a science layout in a large high school. This may be a separate building, or it may be part of a larger building. At the center is a core which contains accessible utilities: water, gas, sewer, electricity.
>
> The several rooms are separated from each other by partitions made of storage cabinets, work counter units, and shelving. These units of furnishings and equipment are spaced about a foot apart, back to back, to provide a "chase" or shaft for utilities to run from the core to the work counters and sink units. Sections 1, 2, 3, and 4 are cross sections showing the "chases" between units of equipment.
>
> Perspective 1 shows the *classroom* side of a unit of furniture located between a science room and a project work room. This unit has storage cabinets in the lower section. The upper section has chalk-boards, which may slide and uncover a picture screen for visual aids. This space might be used for a television screen when such an item becomes available for school use. In addition the sliding chalk-



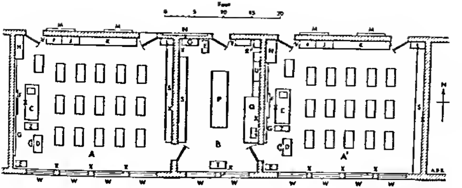
PLAN A


SECTION 1


SECTION 2


SECTION 3


SECTION 4



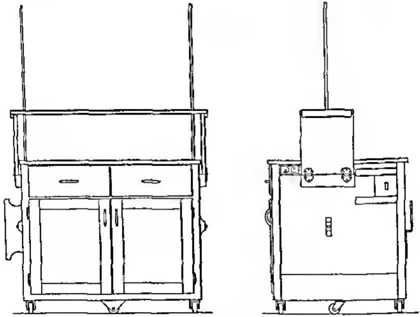
A-A' Classrooms (32 seats, 16 pupil tables, movable)
B Preparation and supply room
C Demonstration table with sink
D Teacher's desk and chair
E Vertical, legal-size letter file
F Shade-type beaded screen
G Blackboard (cork board over)
H Closet for apparatus
I Museum specimen exhibit case
J Closet for general supplies, etc.
K Pupils' clothing wardrobe
L Teacher's clothes locker
M Hall display cork boards
N Hall display case with sliding doors
O Mimeograph machine and table
P Potting bench with storage cabinets
Q Preparation table with peg board over sink
R Bin for storage of glass tubing
S Shelves (bulletin boards over in classrooms)
T Shop workbench with tool storage locker
U Strong safe for projectors, microscopes, etc
V Asbestos blanket
W Windows with double shades, radiators under
X Convenient outlets for 110 v. AC
Y CO_2 fire extinguisher
Z Truck for transportation of apparatus

of a small double-tiered cart (such as is used in the cafeteria to carry dishes). On it were 15 spirit lamps, 15 wash bottles, and 15 empty jars or fruit juice cans for waste. Thus heat, water, and sink were made available; this was adequate for the vast majority of experiments done in general science.

Or you may want to develop your own movable laboratory table. Dr. Newton Sprague, Science Supervisor in the Indianapolis Schools, has developed such a table and provided us with a photograph and drawing of it (p. 510). Plans for its construction and for its equipment may be obtained from him.

Or you may want to develop your own laboratory for general science. Note that the laboratory classroom to be described could be used with splendid advantage for any kind of science teaching. The laboratory was developed by a committee of teachers of the Minneapolis Public Schools, with the guidance of Dr. J. Hervey Shutts, Supervisor of Science. The following description was prepared by this committee and graciously made available to us by Dr. Shutts:

Indianapolis Times



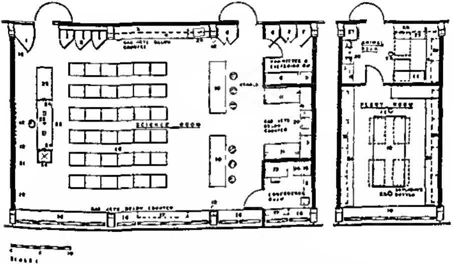
PORTABLE LABORATORY

In the course of planning the Northeast Junior High School science suite, a teacher-planning committee drew up a statement of proposed objectives and layout which they considered optimum. The rooms which were designed to these specifications are shown in the accompanying plan. The numbers on the plan refer to those on the equipment list. An explanation of the diagram follows. The general route of the survey is clockwise around the room beginning with display cabinet numbered one.

1. The upper portion is a display cabinet for student projects. The lower portion of this cabinet area is a storage unit containing a safety shut-off valve for the gas.

2. A series of six cabinets, three above and three below, accommodates collection and return of students' papers, notebooks, and projects. Each of the six cabinets contains thirty-six removable shelves.

3. The wall cases in this part of the room are divided into four sections



EQUIPMENT		LIST	
NO.	DESCRIPTION	NO.	DESCRIPTION
1	DISPLAY CABINET	16	WORK SHELF
2	NOTEBOOK CABINET	17	BOOK SHELVES BELOW
3	WALL CASE	18	DESKS & CHAIRS
4	WORK SHELF & BASE CAB.	19	TACK BOARD
5	PROJECT STORAGE	20	SINK
6	TEACHER'S CLOSET	21	CHALKBOARD
7	EQUIPMENT STORAGE	22	PROJECTION SCREEN
8	TABLE	23	CART
9	PROJECTOR TABLE	24	FLOODLIGHTS
10	WORK TABLE	25	HOSE & BIBB AT CEILING
11	WORK BENCHES	26	DEMONSTRATION DESK
12	FIRE EXTINGUISHERS	27	REFRIGERATOR
13	TEACHER'S DESK	28	ADJUSTABLE SHELVES
14	STANDARD FILE CABINET	29	AQUARIA TABLE
15	JUMBO FILE CABINET	30	PLANT BENCHES

The upper part of the first section, which is nearest the front door, contains the room clock and public address speaker complete with mechanisms, and the lower part is an open shelf useful for a bookcase or placement of semipermanent equipment. The second and third sections of this wall case are cabinets having glass doors for display of small projects mainly of interest to science classes. The fourth section is a blind storage cabinet

4 The student work bench has an alberene stone sink at the right end Underneath the formica surface are storage cabinets with hinged doors. Just below the top and above the cabinet doors is an inset shelf area where gas jets and electrical outlets are mounted Other areas labelled "4" do not have recessed gas and electrical outlets.

5. This is a full length blind storage cabinet.

6 The full length cabinet is for teacher's personal belongings.

7. The full length blind cabinet is for equipment storage.

8. This is a conference table, topped with a carbonized wood finish.

9. This mobile table transports and temporarily stores audio-visual equipment

10. These tables (36" high) are finished with a carbonized wood surface. If the tops are subjected to hard usage, it is recommended that they be covered with a tougher and more resistant surface, such as formica. Each table has three adjustable stools for use at the table. Work table No 10 in the plant room is of very rigid construction with sheet metal top. On this table students mix and condition potting soils One half of the table has a shelf underneath for plant pots, while the other half is left open so that mobile bins containing soil, sand, and fertilizer may be stored there.

11 This laminated hardwood work bench is fitted with vises and blind cabinet storage beneath; gas jets and electrical outlets are recessed under the bench overhang

12 Three foam fire extinguishers hung from brackets are placed in different parts of the room to conform with fire ordinances

13. This particular desk is mainly used by the teacher for preparation and office work.

14 This is a standard file cabinet for storing tests, anecdotal records, correspondence, curriculum guides, etc.

15 The jumbo file cabinet stores such items as clippings and posters

16 Formica covers the surface of this work area The grill work for the entrance of the forced-air heat and ventilation is in the surface near the windows. The area under this shelf contains recessed gas and electrical outlets. This is not true of shelf No. 16 in the conference room and plant room The space under the work area is blind cabinet storage.

17. These portions under the workshelf area (No 16) are open book shelves The shelves in the conference room are for the teacher's personal reference books The book shelves in the science room proper are for reference sets and other supplementary materials

18. The student desks have tubular steel frames with laminated maple fixed tops (18" × 24") and metal book shelves four and one-half inches below the tops These may be placed back to back to make desirable committee or laboratory tables The student chairs have tubular steel frames with laminated wood seats and backs.

19 Two sections of stationary tackboard are located at either end of the chalk board at a height which insures visibility over the demonstration desk.

20 The two alberene stone sinks on the side of the room and in the back have small drainboard areas on either side. They are fitted with hot and cold water, delivered through mixer faucets. One cold-water faucet is permanently

fitted with an air aspirator. Alberene stone was used in the construction of the sinks to make them easy to clean. The drain pipes and trap are made of Duriron, which is especially resistant to chemical action

21. The lower edge of the chalk board is located forty two inches above the floor so that the entire area may be seen over the demonstration desk.

22. A screen on a spring roller in a dust shield is mounted on the ceiling just in front of the chalk-board.

23. The four-wheel cart is the same height and width as the demonstration desk; only two of the wheels swivel and can be locked in place The cart, closed on three sides and open on the fourth, enables the teacher to transport heavy equipment, to prepare demonstrations previous to use in classes, and to extend the size of the demonstration desk.

The cart in the animal room is quite different from the one in the science room proper. This alberene stone topped, mobile table is for transportation of animal cages. Its two drawers store small tools and supplies needed for animal care

24. A series of four adjustable floodlights, mounted on the ceiling, may be centered over any part of the demonstration desk, thus allowing the teacher to make objects easily visible to students

25. This hook and ring, welded to one of the main steel I beam supports of the ceiling and centered over the demonstration desk, is useful in pendulum and pulley demonstrations.

26. The demonstration desk has an alberene stone top fitted with two imbedded steel support rod inserts Gas and electrical outlets are placed under the overhang of the top of the teacher's side Underneath the desk tops are two cabinets for blind storage on either side of a tier of four drawers. The height of the demonstration desk is forty two inches.

27. The refrigerator in the animal room is useful for storage of animal food and specimens for dissection.

28. The open shelves in the plant and animal rooms store animal cages and potted plants.

29. This mobile aquaria table with stainless steel top holds six six-gallon aquaria and can be used to store or transport aquaria from room to room.

30. The plant bench, constructed from wide angle iron and short rot resistant cypress boards, is similar to the type used in modern greenhouses.

In addition to the foregoing explanations of equipment, there are a few other construction details which perhaps need clarifying.

All shelves in cabinets 3, 4, 5, 6, 7, and 26 are adjustable.

The floors of the science room proper are concrete covered with asphalt tile. . . . The floors of the plant and animal rooms are sealed and sloped concrete, with floor drains at the lowest level This arrangement makes cleaning easier.

The ceiling lights of the science room proper are controlled by three switches near the front door. In addition, the middle section of lights may be controlled by a switch near the back door and on the front end of work bench No 11. This facilitates the convenient operation of the lights by the teacher and/or a visual projectionist. The light in the conference room and the committee and listening room is controlled by a separate switch.

There are electrical outlets approximately every eight feet throughout the classrooms. In the animal room and plant room, they are in the wall over the work area.

The room telephone is mounted near the front door.

Ventilation in the committee and listening room, plant room, and animal room is supplemented by separate fan systems. The plant room and the animal room also have fresh air vents that open to the roof.

Venetian blinds are inadequate for darkening the room for audio visual projection Sets of opaque shades on all windows are necessary.

The partitions separating the committee and listening room and the conference room from the science room proper are transparent glass from three to seven feet high A similar glass section is included in the partition between the plant and the animal rooms If opaque shades are provided between the committee and listening room and the science room proper, and if one of these shades has a flat white finish toward the conference room, pictures may be projected on it.

Skylights with adjustable shades placed in the ceilings of the plant and animal rooms afford natural light

All ceilings are acoustically treated. In future plans, insulation to sound transfer should be provided under work benches No. 11 to prevent passage of work noises to room on lower floors.

A roof area easily accessible by convenient stairway is provided for weather and star observations.

The two doors in the science room conform to existing safety and fire standards.

Renovation. Very likely you would like to have one or more features of these classrooms in your own, but your room is built and will be used for years to come. Yet renovations are continually being made, and some of these features can be written into the schedule of alterations. Others could be provided by modest purchases or by local construction; in several schools students have made mobile equipment carts and portable "laboratories" with heat, water, and electrical outlets for use in rooms not so equipped.

If the school board is not able to finance some of the modest changes you wish, do not forget the Parent-Teachers Association, local service clubs, and local industries as possible sources of small funds for specific purposes.

Directory of suppliers

Standard equipment, such as chemicals, glassware, charts, models, microscopes, slides, stains, living and preserved materials may be purchased from the supply houses suggested in this list. Their catalogues will be useful.

- Aloe Scientific, Division of A S Aloe Co , 5655 Kingsbury Ave., St Louis 12, Mo.; also Atlanta, Kansas City (Mo), Los Angeles, Minneapolis, New Orleans, San Francisco, and Washington, D. C.
- American Hospital Supply Corp , 40 05 168 St., Flushing, N. Y ; or 2020 Ridge Ave., Evanston, Ill. (blood typing serums)
- American Optical Co , Buffalo 15, N. Y.
- Baltimore Biological Laboratory, Inc., 1640 Gorsuch Ave , Baltimore 18, Md.
- Bausch and Lomb Optical Co , 635 St. Paul St , Rochester, N. Y
- Biddle & Co , *1316 Arch St , Philadelphia 7, Pa.* (laboratory supplies)
- Biological Research Products Co , 3829 S Morgan St , Chicago 9, Ill.
- Cambosco Scientific Co , 37 Antwerp St , Brighton 35, Mass.
- Carolina Biological Supply Co , Elon College, N C.
- Central Scientific Co , 1700 W. Irving Park Road, Chicago 13, Ill.
- Certified Blood Donor Service, 146-16 Hillside Ave , Jamaica 35, N. Y. (blood-typing serums)

The professional library

There are many fine books which should be in a school library, or in the science teacher's library. A library, of course, is never complete; useful books are constantly being written; discoveries in science and in science education are constantly being made.

We could not begin to list the books available; neither would we want to prescribe a list of titles. What we shall do is to indicate where a teacher should look as he goes about *building a science and science education library.*

1. Consult with librarians in your school and others nearby, as well as in public libraries. They can tell you which books are consulted most often, which are most useful, and which are rarely used. You might also ask a librarian to check lists of books that you prepare from other sources.

2. The catalogues of the different publishing houses yield not only titles of books and other publications, but usually thumbnail descriptions.

3. A nearby college or university will probably have a library which may be a template for the one you wish to develop.

4. Any book or journal on the subject will give references; one book leads to the next.

5. You may want to ask seniors in a science club or a science project group to look through available textbooks (both high school and college), teachers' manuals, journals, and compile a list of suggested books for the library.

6. Your Parent-Teachers Association may have a library committee to help do the same thing.

7. The two volumes accompanying this one contain bibliographies.

8. There are also the books of the Traveling High School Science Library. Information may be obtained from: High School Traveling Science Library Program, American Association for the Advancement of Science, 1515 Massachusetts Ave , N.W., Washington 5, D. C

9. We list in this section some basic references on the teaching of science, some suggested references on methods and procedures of teaching science, some professional journals (some on science teaching, some on various fields of science proper), and finally a listing of paperback books in science, which may find a place in a professional library as well as in a student reading corner.

In a very short time a full professional library can be built up in the school—a continuing resource for the improvement of science teaching.

Some basic references on the teaching of science

Certain publications have had such strong influence upon the direction of science teaching efforts that they should be known to all teachers. Among those of the greatest importance are, in historical order.

1894 *Report of the Committee of Ten on the Reorganization of Secondary Schools*, N. Y.: World Book, 1894

1918 *Cardinal Principles of Secondary Education*, Report of Commission on the Reorganization of Secondary Education, Washington, D. C.: U. S Office of Education Bulletin 35, 1918.

1920 *Reorganization of Science in Secondary Schools*, Washington, D C.: U. S. Office of Education Bulletin 26, 1920

1932 National Society for the Study of Education, *Thirty First Yearbook*, Part 1, *Program for Teaching Science*, Chicago U. of Chicago Press, 1932

1938 Progressive Education Association, *Science in General Education*, N. Y.: D. Appleton-Century Co., 1938.

1942 Croxton, W. C., *Redirecting Science Teaching in the Light of Personal Social Needs*, Washington, D. C National Education Association, 1942.

1944 Educational Policies Commission. *Education for ALL American Youth*, Washington, D. C.: National Education Association, 1944

1947 National Society for the Study of Education, *Forty Sixth Yearbook*, Part 1, *Science Education in American Schools*, Chicago U of Chicago Press, 1947

1953 "Science in Secondary Schools Today,' *National Association of Secondary-School Principals Bulletin*, Vol. 37, No. 191, Jan. 1953.

Some suggested references on methods and procedures in teaching high school science

Blough, G., and M. Campbell, *Making and Using Classroom Science Materials*, N. Y.: Dryden, 1954.

Burnett, R. W., *Teaching Science in the Secondary School*, N Y: Rinehart, 1957.

Elder, A., *Demonstrations and Experiments in General Chemistry*, N. Y: Harper, 1937

Fowles, G, *Lecture Experiments in Chemistry*, N. Y.: Blakiston (McGraw-Hill), 1948.

Heiss, E., E. Obourn, and C. Hoffman, *Modern Science Teaching*, N Y.: Macmillan, 1950.

Hoff, A, *Secondary Science Teaching*, rev. ed, N. Y.. Blakiston (McGraw-Hill), 1950.

Jersild, A. T., and R. J. Tasch, *Children's Interests and What They Suggest for Education*, N. Y.: Bur. Publications, Teachers College, Columbia U., 1949.

Miller, D., and G. Blaydes, *Methods and Materials for Teaching Biological Sciences*, N. Y.: McGraw-Hill, 1938.

Richardson, J., *Science Teaching in Secondary Schools*, Englewood Cliffs, N. J.: Prentice Hall, 1957.

——, and G. Cahoon, *Methods and Materials for Teaching General and Physical Science*, N. Y.: McGraw-Hill, 1951.

Science Clubs of America, *Sponsors' Handbook: Thousands of Science Projects*, Science Service, 1719 N St., N.W., Washington 6, D. C.

Sutton, R., *Demonstration Experiments in Physics*, N. Y.: McGraw-Hill, 1938.

Swezey, K., *After-dinner Science*, N. Y.: McGraw-Hill, 1952.

Weisbruch, F., *Lecture Demonstration Experiments for High School Chemistry*, St Louis. Educational Pub., 1951.

Wells, H, *Secondary Science Education*, N. Y.: McGraw Hill, 1952.

Some journals and magazines of interest to science teachers

American Biology Teacher
Interstate Press
19 North Jackson St
Danville, Ill.
$3 75/year

American Journal of Physics
American Institute of Physics
335 East 45 St
New York 17, N Y.
$7 50/year

Chemical and Engineering News
American Chemical Society
1155 16 St, N.W
Washington 6, D C
$6 00/year

Journal of Chemical Education
20 and Northampton Sts
Easton, Pa.
$3 50/year

Mathematics Teacher
National Council of Teachers of Mathematics
1201 16 St, N.W.
Washington 6, D C.
$3 00/year

Natural History Magazine
American Museum of Natural History
79 St and Central Park West
New York 24, N. Y.
$5.00/year

School Science and Mathematics
Box 408
Oak Park, Ill.
$4 50/year

School Science Review
S W. Read, 31 Grosvenor Road
Chichester, Sussex, Eng
£1/year

Science Counselor
Duquesne University
901 Vickroy St.
Pittsburgh 19, Pa.

Science Education
374 Broadway
Albany, N Y.
$5 00/year

Science News Letter
Science Service
1719 N St., N.W.
Washington 6, D. C
$5 50/year

Science Teacher
National Science Teachers Association
1201 16 St., N.W.
Washington 6, D. C
$6 00/year regular member
$10 00/year sustaining member

Scientific American
415 Madison Ave.
New York 17, N. Y.
$5 00/year

Science
1515 Massachusetts Ave, N.W.
Washington 5, D. C.
$7.50/year

Sky and Telescope
Harvard Observatory
Cambridge 38, Mass.
$5 00/year

Turtox News
General Biological Supply House
761 East 69 Pl
Chicago 37, Ill.
Free

Weatherwise
American Meteorological Society
3 Joy St.
Boston 8, Mass.
$4 00/year

Welch Physics and Chemistry Digest
Welch General Science and Biology Digest
W. M Welch Scientific Company
1515 N. Sedgwick St.
Chicago 10, Ill.
Free

Yearbooks of the United States Department of Agriculture
Washington, D C.
Through your congressman.

Paperback books in science

PRIMARILY CHEMISTRY	AUTHOR	PRICE (SUBJECT TO CHANGE)	PUB-LISHER *
Alchemy	Holmyard	.85	Pen
Chemical Industry	Williams	.50	Pen
Chemistry	Hutton	.85	Pen
Crucibles	Jaffe	.35	Prem
New Chemistry	Scientific American	1.00	S&S
Organic Chemistry	Degering *et al.*	1.75	B&N
Physical Chemistry	Kittsley	1.50	B&N
Metals in the Service of Man	Street	.85	Pen
PRIMARILY PHYSICS			
Automatic Control	Scientific American	1.00	S&S
Atomic Power	Scientific American	1.00	S&S
Dialogues Concerning Two New Sciences	Galileo	1.65	Dov
Matter and Light	de Broglie	1.75	Dov
Physics: First Year College	Bennett	1.25	B&N
Physics Made Simple	Freeman	1.00	Made
Revolution in Physics	de Broglie	1.65	Noon
Rise of the New Physics (2 vols.)	D'Abro	3.90	Dov
Science of Flight	Sutton	.85	Pen
Our Friend the Atom	Haber	.35	Dell
Optics	Newton	1.98	Dov
PRIMARILY BIOLOGY			
Human Use of Human Beings	Wiener	.75	Anch
Origin of Species	Darwin	.95	Ungar
Physics and Chemistry of Life	Scientific American	1.00	S&S
Sea Around Us	Carson	.35	NAL
Elements of Physical Biology	Lotka	2.45	Dov
General Biology	Alexander	1.25	B&N
Genetics	Kalmus	.50	Pen
Living Tide	Berrill	.35	Prem
Fascinating Insect World of Fabré	Teale	.35	Prem
General Zoology	Alexander	1.50	B&N
General Botany	Fuller	1.00	B&N
Plant Life	Scientific American	1.00	S&S
Bees	von Frisch	1.45	Corn
Dictionary of Biology	Johnson & Abercrombie	.65	Pen
Atomic Radiation and Life	Alexander	.85	Pel
PRIMARILY HISTORY AND PHILOSOPHY			
Concerning the Nature of Things	Bragg	1.25	Dov
Evolution of Scientific Thought	D'Abro	2.00	Dov
Magic, Science, and Religion	Malinowski	.95	Anch
Foundations of Experimental Science	Campbell	2.95	Dov
Copernicus to Einstein	Reichenbach	.95	WL

* Code of publisher; see list of publishers which follows this list.

	AUTHOR	PRICE (SUBJECT TO CHANGE)	PUB-LISHER
From Magic to Science	Singer	1.65	Dov
Great Essays in Science	Gardner	.35	PB
Lives in Science	Scientific American	1.00	S&S
Man on His Nature	Sherrington	.95	Anch
What is Science?	Campbell	1.25	Dov
New Worlds of Modern Science	Engel	.35	Dell
What Happened in History	Childe	.85	Pen
The Arabs	Hitti	.95	Gate
Science and Hypothesis	Poincaré	1.25	Dov
Greek Science	Farrington	.65	Pen
Experiment and Theory in Physics	Börn	.60	Dov
Foundations of Physics	Lindsay & Margenau	2.45	Dov
What Is Life?	Schrödinger	.95	Anch
Nature of Physical Theory	Bridgman	1.25	Dov
PRIMARILY ASTRONOMY AND GEOLOGY			
Astronomy	Miller	1.00	Bell
Biography of the Earth	Gamow	.50	NAL
Birth and Death of the Sun	Gamow	.50	NAL
Creation of the Universe	Gamow	1.25	Comp
Discover the Stars	Johnson & Adler	.75	Sent
Discoveries and Opinions of Galileo	Drake	1.25	Anch
Exploration of Space	Clarke	.35	PB
Frontiers of Astronomy	Hoyle	.50	NAL
Key to the Heavens	Mattersdorf	.35	Prem
Life on Other Worlds	Jones	.50	NAL
Nature of the Universe	Lucretius	.65	Pen
New Astronomy	Scientific American	1.00	S&S
Origin of the Earth	Smart	.65	Pen
Universe	Scientific American	1.00	S&S
One Two Three—Infinity	Gamow	.50	NAL
World of Copernicus	Armitage	.50	NAL
History of Astronomy, Thales to Kepler	Dreyer	1.98	Dov
Birth and Development of Geological Sciences	Adams	2.00	Dov
Dictionary of Geology	Himus	.50	Pen
Geology in the Service of Man	Fearnsides & Bulman	.50	Pen
How to Know the Minerals and Rocks	Pearl	.50	NAL
Principles of Geology	Field	1.25	B&N
Rocks and Minerals	Pearl	1.95	B&N
Universe & Dr. Einstein	Barnett	.35	NAL
MATHEMATICS			
Non Euclidean Geometry	Bonola	1.95	Dov
Number, the Language of Science	Dantzig	.95	Anch
Prelude to Mathematics	Sawyer	.65	Pen
Principles of Relativity	Einstein *et al.*	1.65	Dov

	AUTHOR	PRICE (SUBJECT TO CHANGE)	PUB-LISHER
Statistical Methods	Arkin & Colton	1.75	B&N
The Elements (3 vols.)	Euclid	5.85	Dov
Analytic Geometry	Oakley	1.25	B&N
Asymptotic Expansions	Erdelyi	1.35	Dov
Calculus	Petersen & Graesser	1.75	Lita
College Algebra	Feinstein & Murphy	1.75	Lita
College Algebra	Moore	1.50	B&N
Descriptive Geometry	Slaby	2.25	B&N
Dictionary of Mathematics	McDowell	1.45	WL
Famous Problems of Elementary Geometry	Klein	1.00	Dov
The Geometry	Descartes	1.50	Dov
Geometry of Four Dimensions	Manning	1.95	Dov
Introduction to Theory of Groups	Carmichael	2.00	Dov
Introduction to Theory of Numbers	Dickson	1.65	Dov
Mathematics, Magic, and Mystery	Gardner	1.00	Dov

Anch Anchor Books, Doubleday & Co., 575 Madison Ave., New York 22, N. Y.
B&N Barnes & Noble, 105 Fifth Ave., New York 3, N. Y.
Bell Bellman Publishing Co., P. O. Box 172 Cambridge 38, Mass.
Comp Compass Books, Viking Press, 625 Madison Ave., New York 22, N. Y.
Corn Cornell University Press, 124 Roberts Pl., Ithaca, N. Y.
Dell Dell Publishing Co., 750 Third Ave., New York 16, N. Y.
Dov Dover Publications, Inc., 920 Broadway, New York 10, N. Y.
Gate Gateway Books, Henry Regnery Co., 64 E. Jackson Blvd., Chicago 4, Ill.
Lita Littlefield, Adams & Co., 128 Oliver St., Paterson 1, N. J.
Made Made Simple Books, Doubleday & Co., 575 Madison Ave., New York 22, N. Y.
NAL New American Library, 501 Madison Ave., New York 22, N. Y.
Noon Noonday Press, 80 E. 11 St., New York 3, N. Y.
PB Pocket Books, Inc., 630 Fifth Ave., New York 20, N. Y.
Pel Pelican Books, see Penguin address
Pen Penguin Books, Inc., 3300 Clipper Mill Rd., Baltimore 11, Md.
Prem Premier Books, Fawcett Publications, Inc., 67 W. 44 St., New York 36, N. Y.
S&S Simon and Schuster, 630 Fifth Ave., New York 20, N. Y.
Sent Sentinel Books, 112 E. 19 St., New York 3, N. Y.
Ungar Frederick Ungar Publishing Co., 105 E. 24 St., New York 10, N. Y.
WL Wisdom Library, Philosophical Library, Inc., 15 E. 40 St., New York 16, N. Y.

A listing of paperbound books in science is published by the American Association for the Advancement of Science, 1515 Massachusetts Ave., N.W., Washington, D. C. You will find more extensive listings in *Paperbound Books*, R. R. Bowker Co., 62 W. 45 St., New York 36, N. Y. The latter is a complete list of paperback books in print; the cost is $3.00 a year for this catalogue in two (spring and fall) editions.

The expert, with a note on becoming one

Experts will, no doubt, object to being included in a section on "tools." We appeal to their sense of humor; experts know that their effectiveness depends on how they are used.

Our purpose here is to indicate briefly that the teacher is not alone; he can call on people with experience. Whether the experience is transmitted in a useful way to the teacher depends on the choice of consultant, the specificity of the problem, and the completeness of the information offered to him. Naturally, the opportunity to use the advice or the competence the consultant transmits also depends on conditions within the school.

Where does one find experts?

1. In the school or school system:
   a. Chairmen of Departments.
   b. Consultants in science in the school, or within the School Department or State Department of Education.
   c. Senior teachers.
   d. Teachers with special experience, e.g., in particular subjects, in audio-visual aids, in testing, in guidance, in library work.
2. In the community:
   a. Experts in the university or college, state and federal departments.
   b. Experts in the city government, e.g., Board of Health (doctors, nurses, and engineers).
   c. Experts generally in the community, itself, e.g., doctors, engineers, technicians, especially those retired.
   d. Experts in local industries and businesses.
3. In the nation:
   a. Specialists in testing.
   b. Specialists in facilities
   c. Specialists in teaching, in administration, in curriculum.

There is need for consultants. Any teacher who becomes an expert will find himself in demand.

On becoming an expert. Every teacher becomes an expert sooner or later, in a small area or a large one. For instance, a teacher may be: an expert in dealing with visual aids, with reading materials, with demonstrations, with

the science shy, with the science prone, with student teachers, and with "problem students." An expert knows more than most people about a given area. A teacher who is an expert, and who, in addition, is skillful in communicating his expertness, will soon be in demand in his community and the nation.

Helping others become experts. No doubt you have or will soon have a student teacher in your classes, or a young science teacher will seek your advice, or a student in your class will want to become a science teacher. What kind of training should any beginning or prospective teacher have?

Recommendations for the training of teachers come from all sides. Here is one you may want to consider: [1]

> During the last twenty years certain criteria for adequate preparation of science teachers have been proposed by individuals and groups which included academic people, scientists and educators. In about twenty such reports there is concurrence on seven general recommendations. These, as listed below, might well be considered by those attempting new steps in the development of teacher certification requirements and teacher training programs. There is concurrence that:
>
> *1. required programs and the courses composing them ensure that the prospective teacher has a scholarly mastery of the fields to be taught,*
>
> *2. the prospective teacher have a knowledge of education, including such aspects as the nature and development of the child and adolescent learner, testing methods, and evaluation;*
>
> *3. skill and competence in teaching be developed as far as possible through realistic experience with actual problems which arise in schools and communities,*
>
> *4. the prospective teacher have contact with all major areas of human knowledge. Specialization is not enough. The teacher should become aware of the interactions of his major field of study with other fields of human endeavor and creative thought;*
>
> *5. the five-year training program for teachers become a mandatory minimum,*
>
> *6. nation-wide or at least regional standards for teacher certification be adopted, and better methods of appraising teacher competence be found;*
>
> *7. during the training process, a sense of self-criticism be instilled in the prospective teacher, so that later he may have the ability to evaluate himself and his work.*
>
> That competence in major fields plus professional education is not impossible to achieve in a five-year program is evidenced by the requirements for the comprehensive and specific restricted teaching licenses in Indiana. There, a prospective teacher must have 40 semester hours of study in the physical or biological sciences to earn a comprehensive license. For the additional restricted license to teach a particular subject, for example, physics, 24 more hours of work in the field are required. Thus a minimum of 64 semester hours in subject matter courses is required in the four-year undergraduate program; various patterns of courses ensure both breadth and depth. Eighteen hours of professional education courses are required, including educational psychology, principles of education, guidance, and special methods. Five additional semester hours of credit are earned for student teaching. As electives, courses are offered in the history and philosophy of education, tests and measurements, and other related subjects.
>
> There are, however, some problems associated with the five-year program for

[1] *Critical Years Ahead in Science Teaching*, Report of Conference on Nation-wide Problems of Science Teaching in the Secondary Schools, ed. by F. Watson *et al.*, Harvard U. Press, Cambridge, 1953, pp. 39-41.

science teacher preparation. Teachers who aim at the Master of Arts or Science degree often find that their background in a particular subject is insufficient to allow them to enroll in graduate courses, or to compete with undergraduates who have completed far more semester hours of study. Such courses, designed for the future specialist in the field, may have less usefulness to a teacher than would similar courses designed explicitly for teachers. There are also problems raised by time and money. Lack of time often makes it difficult for an employed teacher to carry through an investigation meeting degree requirements, while lack of funds often prohibits the teacher from investing another year or more in full time graduate study.

We need teachers who have an awareness of scientific problems, who grasp every opportunity to encourage an inquisitive pupil toward further study and investigation, who know how to direct laboratory work and student projects, and who have a desire to make science classes a stimulating part of every high school curriculum.

Tools for the science teacher **18**

The resource file: where to go for further help

Over the first five years of his teaching, one teacher gathered the following:

1. A file of teaching techniques (see 5).
2. Catalogues of films and filmstrips (renewed as new ones were published by having himself put on the mailing lists of the companies concerned; see directory of such companies on pp. 481-82).
3. Catalogues of scientific equipment (directory of suppliers, pp. 514-15).
4. Pictures from regularly published magazines, newspapers, and industrial magazines (used for bulletin board materials. included pictures of the widest variety of topics—scientists, animals, plants, new machines, satellites).
5. Files of the magazines and journals of the societies to which he belonged. In file of teaching techniques (1) were index cards, relating to specific issues.
6. A library (see p. 516).

One of the most useful tools for the teacher is a file which is also used by other teachers in the department, or even in the school. Of course, other teachers also contribute to it. One type of file consists of large file cards, each of which has an approach to teaching, a learning situation, or a valuable reference to a film, a book, a quotation, a test—whatever device is useful in teaching. For instance, two cards might contain the following information:

Field: *Astronomy*

Topic: Solar System

In approaching the teaching of astronomy, it is useful to use a basketball. Students in a circle throw the ball west to east, east to west. Discussion follows: Which way does earth revolve around sun?

Also useful in illustrating rotation and seasons.

Field: *Projects*

Topic: Photosynthesis

What happens to "gas" output of elodea in "colored" light?

Tubes of elodea may be masked with green, red, blue plastic or cellophane (possibly useful for science fair).

You may remember that such a card file was also suggested for developing test items (p 432) It doesn't take long to see how exceedingly valuable such a file can become Every useful device may be recorded, and within a relatively short time (considered in the span of the teacher's career), a valuable resource file is obtained, especially if several teachers collaborate.

The items to be placed in the file depend, of course, on the particular desires of the teacher and the particular function of the school.

Many of the procedures a teacher may find useful are described in the accompanying volumes, *A Sourcebook for the Biological Sciences* and *A Sourcebook for the Physical Sciences.*

Other source materials and sources of materials are obtained from the following organizations devoted to the improvement of teaching. Of course, we cannot list local organizations, but we have obtained help of all sorts—funds, equipment, consultants, special teachers, guidance, and consolation—from such local organizations as the local Parent-Teachers Association, local industry, nearby colleges and universities, community government, skilled personnel (doctors, engineers, teachers, both "active" and "retired").

Why not acquaint yourself with the materials or services of the following national organizations: [1]

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE. Junior Academies of Science are encouraged through the AAAS-affiliated state and city Senior Academies of Science. A Junior Scientists Assembly is sponsored each year at the annual Christmas meeting. Grants are given for student projects through the Senior Academies. Write to Dr. R. L. Taylor, Associate Administrative Secretary, AAAS, 1515 Massachusetts Ave., N.W., Washington 5, D. C.

AMERICAN CHEMICAL SOCIETY. Each year about 4,000 of the 80,000 ACS members volunteer to give personal assistance to high school science teachers upon request. These people work through the 151 local sections of the Society. If you as a teacher want further information about careers in chemistry or chemical engineering, summer employment opportunities, speakers, consultants, and the like, consult the local section officers in your area. Their names and addresses and other information can be obtained from: American Chemical Society, 1155 16 St., N.W., Washington 6, D. C.

AMERICAN MEDICAL ASSOCIATION. County and state medical societies cooperate with local science fairs by joining in sponsoring committees, giving special awards and scholarships, providing transportation to the National Science Fair, arranging counseling, and so forth. The American Medical Association presents four citations at the annual National Science Fair and the two top AMA award winners are guests at the AMA annual meeting. For information and names of local medical society officers, write to Leo E. Brown, American Medical Association, 535 N. Dearborn St., Chicago 10, Ill.

CHAMBER OF COMMERCE OF THE UNITED STATES. Over 1,800 Chambers of Commerce now have Committees on Education. These committees have been alerted to the nation's manpower problems and to the need for better career

[1] Most of this information was collated by Science Service (see pp. 529 30).

The principal should register for administering the Scholarship Qualifying Test (Science Research Associates, 57 W. Grand Ave., Chicago 10, Ill.) before October 1. Two students or five per cent of the senior class are tested without charge, and others may take the test upon payment of a fee of $1.00. The test is given late in October at each participating school. For additional information, see your principal, or write National Merit Scholarship Corporation, 1580 Sherman Ave., Evanston, Ill.

NATIONAL SCIENCE FAIR. About a quarter of a million young scientists in junior and senior high schools annually undertake science projects and build exhibits to be shown in thousands of science fairs in their high schools. The best of these compete in some 150 local and regional science fairs, which send in May their two top finalists, usually a boy and a girl, to the National Science Fair, conducted by Science Service. The National Science Fair is held in a different city each year; visit it when the Fair is near you. Local organizations, including newspapers, public, private, and parochial schools, colleges, industries, scientific and technical societies, clubs, and many others cooperate in local and regional fairs. Science fair participation inspires and develops youthful science talent. Science Service offers full information and "know-how" in conducting science fairs, arranges cooperation of organizations like American Medical Association and its state and county societies. Write Science Service, 1719 N St., N.W., Washington 6, D. C.

NATIONAL SCIENCE FOUNDATION. This agency of the federal government conducts an extensive program of support and stimulation to science and research, including scientific personnel and education. Most of its operations are through grants that facilitate activities by other organizations. Extensive programs include the support of institutes for science and mathematics teachers in high schools and colleges, and the program for graduate fellowships. Announcements are available from time to time. National Science Foundation, Washington 25, D. C.

NATIONAL SCIENCE TEACHERS ASSOCIATION. A department of NEA, and an affiliate of the AAAS, this organization offers publications to help stimulate science activities by students, such as:

Tomorrow's Scientists—for high school science students. Group subscriptions are 50¢ each, minimum of 5 subscriptions to one address ($2.50). Individual subscriptions are $1.00.

Encouraging Future Scientists: Student Projects—examples of prize-winning science projects done by students. Single copies, 50¢ each. Quantity orders, 25¢ each.

If You Want To Do a Science Project—suggestions to help students plan, carry through, and report science projects. Single copies, 50¢ each. Quantity orders, 25¢ each. (All orders for $1 or less must be accompanied with remittance.)

Encouraging Future Scientists: Keys to Careers—bibliography of science career information and guidance materials. Single copies free.

Careers in Science Teaching—pictorial presentation of science teaching as a career. Single copies free.

Section Six

BLUEPRINTS FOR COMMUNITY ACTION

Community as a word, or concept, has often oppressed the teacher. He hears. He must meet the needs of the children in the particular community in which he lives. He reads: Co-operation with the community is essential to the fullest development of the school program. He learns No school program can develop to its fullest without the knowledge and collaboration of the community. And eventually he realizes A school or school system solves its problems best and with optimum speed when the community is a part of the school, when the community helps in shaping the objectives of the school and glories in their realization. The school is created by its community and it is sustained by it. In the school situation not only "where there is a will, there is a way," but also "where there is a good community-school relationship, there is a way."

We have maintained that a teacher's method is his personal invention, contrived from his culture, his heredity, his environment, his training, and the thought he puts into developing an imaginative approach to teaching. We have maintained that a school curriculum is a personal invention of a faculty working with the community and with the children who are to do more, learn more, and know more.

Now each community has its own way of doing things· It flavors the present out of its past. But in the long run, deep-rooted changes in school practice are developed through the energetic, intelligent, and effective labor of the community to reach its goals.

We present three such attempts at improving science education in three different kinds of communities. We have not excerpted or updated the reports; we reproduce them as they were originally drafted to preserve their special flavor; for the flavor of a report indicates how the community may address itself to a problem. Nor have we commented upon them; we present them simply as examples of how three different communities attack essentially the same problem: How to improve instruction in science.

The moral to be derived from the three stories is also essentially the same, despite differences in approach: To improve science instruction—as indeed all instruction—the active interest and collaboration of the community assures that the problems will be faced. And, if it is within the scope and responsibility of the community and the school, the problems will be solved.

Search, National Science Fair, etc. Free material available on various activities and samples of publications sent on request.

Science News Letter, weekly summary of current science, \$5.50 a year, trial \$3.13 for 41 weeks.

Chemistry, nine times a year, \$4 a year.

Things of Science, monthly experimental kits, actual samples of novel and educational material, membership \$5 a year, collection of 29 kits, \$13 50.

Thousands of Science Projects, listing titles of exhibits actually made, 25¢ a copy, 10 copies for \$1

Science Service books, each \$2 postpaid.

Science Exhibits

Scientific Instruments You Can Make

The Chemistry We Use

Organic Chemistry for the Home Lab

Experimenting with Chemistry

Color slides of National Science Fair, 3 sets available, \$6 each.

Science Service, 1719 N St., N W., Washington 6, D. C.

SCIENCE TALENT SEARCH. High school seniors have a chance to win trips to Washington, share in a sizable total in Westinghouse Science Awards and Scholarships, and be recommended for admission and support in college. The Annual Science Talent Search for seniors is held in the fall of each year. Teachers should ask for examinations in October. Seniors should be working on their projects and reports during the summer Completed entries must arrive at Science Service not later than midnight, December 27. Science Talent Search is conducted by Science Clubs of America, a *Science Service* activity, and sponsored by the Westinghouse Educational Foundation. Ask for *How to Search for Science Talent* sent free on request. Science Service, 1719 N St., N.W., Washington 6, D. C.

THOMAS ALVA EDISON FOUNDATION. The Edison Foundation carries on programs directed at encouraging more boys and girls to undertake careers in science and engineering, and also carries on a public information program in behalf of improving the quality and quantity of science education. National Science Youth Day, which is held annually on Thomas Alva Edison's birthday, February 11, is a nation wide program to interest young people in science and engineering. Participating in this National Edison Birthday Celebration are major companies of American industry, governmental agencies, professional, scientific and educational societies, and other groups. Science experiment booklets and other free materials are distributed nationally to students Special student visits to industrial plants and research and development laboratories are arranged. The Foundation also organizes national conferences and Edison Institutes on scientific manpower and science education problems. Awards are also given in the mass media to encourage better program material in sciences. A list of publications available from the Edison Foundation may be secured by writing to Thomas Alva Edison Foundation, Inc., 8 W. 40 St., New York 18.

The Detroit science education story*

SCIENCE EDUCATION: DOES IT PRODUCE OR FRUSTRATE POTENTIAL SCIENTISTS?

DR. SAMUEL M. BROWNELL
Superintendent, Detroit Public Schools

When Mr. Kettering asked me to talk to this Eighth Edison Foundation Institute, I agreed if I could take as my task the discussion of the topic, "Science education: does it produce or frustrate potential scientists?" In the face of this nation's record of producing great numbers of scientists who have helped to develop the world's greatest technological economy and defense program, why raise such a question? It is because we need to increase the efficiency of science education even beyond its present level. We need to secure more better scientists faster.

The need for making better provisions for science education is not a new discovery resulting from Sputnik. What is new is that persons who formerly failed to hear, or who dismissed pleas for action to strengthen science education as propaganda by educational pressure groups, or who considered it desirable but too expensive, are suddenly calling for action. They now see the significance of what has oft been presented. Many of them do not realize that much progress has been made. They believe that because they have just become aware of the problem that the problem is new.

Scientists and educators have been working hard during the past several years to improve and to increase the supply of scientists, engineers, and mathematicians, and the results are encouraging. Greater progress can and must be made. Some immediate adjustments can increase the output of scientists, engineers, and mathematicians somewhat. But the major job of permanently increasing the number of leaders in science and in other fields from able young people who do not go far enough in school or prepare themselves sufficiently well to be scientists or other leaders needs to be considered in terms of decades, not of months and years. It involves improving the preparation of those who teach mathematics and science in the elementary schools as well as in high school and in college. It requires changing the attitudes of some families toward the study of science and toward the preparation of girls for scientific careers. It calls for the provision of more adequate school facilities and better pay and status for teachers so that pupils in elementary schools, high schools, and colleges receive high quality instruction.

These changes cannot come about as the quick result of a "crash" program and thus solve our science manpower shortage. It may be, however, that we need a program sudden enough and large enough to crash through existing barriers and initiate these changes without delay. The problem then facing us is to sustain through the

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tence in science, as it does in athletics, music, writing, or craftsmanship in any field. Failure to provide sufficient immediate and long range rewards in the study of science or mathematics may be as effective in closing the door to further advance of a youth as exclusion from schooling. Furthermore, since there are not enough among those of high ability who decide very early that they want to be scientists, mathematicians, or engineers, and who now stay on to become scientists or mathematicians, we must provide opportunities to enter these specializations for those who have high ability and who develop serious science concerns at differing ages, or who resume scientific interest after a lapse of time.

Another effective preventative to advancement of students may be discouragement resulting from working in a class taught by a teacher of science or mathematics who measures his success by the number of pupils he fails instead of by the number he prepares for, and interests in, going on to the next course that is offered in the curriculum

Where great differences exist in the mortality or failure rate between teachers who have pupils of equal ability, investigation of the causes is in order lest doors are being closed which should be left ajar or kept open

The good teacher has traditionally been one who increased the interest and effort of an able pupil by providing opportunities for him to move ahead in his thinking and learning as rapidly as he was able This good teacher has removed road blocks and opened new paths beyond what might be available in the prescribed classwork Organization of courses of study to aid teachers in systematic science and mathematics instruction is essential, but there is ever present the danger that too slavish following of a pattern of organization which seems logical to the teacher may frustrate the ingenuity and initiative of the bright pupils Special groupings for high ability pupils and freedom for such pupils to work independently seem possible to a greater degree than presently found in practice.

These examples are the kinds of practices that schools and colleges ever need to examine carefully to see if some teachers and some administrative practices operate to close doors that could and should be opened or reopened to potentially able scientists.

A third way in which schools and colleges may be frustrating some potential scientists may be through *making other portions of schooling more rewarding, or science less rewarding, for equal expenditure of time and energy.*

For years students who have enrolled in laboratory science courses have been required to spend more clock hours in class and laboratory combined for a given amount of credit toward graduation than required for nonlaboratory courses. And, in order to schedule double laboratory periods, students were more likely to find it necessary to have them at times that were in competition with extracurricular activities or to take sciences at the deprivation of study periods which other students have.

Another situation has grown up in many schools or campuses in which, for equivalent expenditure of time and energy and quality of performance, pupils receive higher grades in subjects other than the sciences and mathematics. Ambitious high school students wish to have a good high school academic record because it may affect their college entrance. Able college students know that college honors and chances beyond college depend somewhat on their academic record. Such students are thus placed in the position where to choose work in science or mathematics (which they may like as well as some other area) they know will produce a less favorable record for them. Thus when we hear criticisms today that students choose *soft* rather than *hard* courses we need to consider how much of this is due to the way in which schools and colleges operate. I submit that the idea that some areas of study are inherently harder than others needs to be examined critically to see if what is involved is not inequity in the way science is treated compared with other subjects in the curriculum, and inequality in evaluation of equivalent student work as between different instructors.

progress. The science or mathematics teacher who measures his success by the number of pupils who take *more* math or *more* science has indeed a standard that is far more significant than the grade on examinations, or the number or per cent failed. Factual knowledge learned is of little import *if it is the end product. Desire to learn more* about a subject and skill to pursue investigation in that field is far harder to develop but leads to real learning. It is the goal of the true teacher at the elementary school, high school, or college level.

It is in the elementary school that attitudes toward learning are substantially built or curbed even though many other influences than the teacher may interest or distract the interest of a pupil in the different fields open to him for study. Many scientists can trace their awakening of interest in science or mathematics to an elementary school teacher, yet *the fact is that there are many elementary school teachers teaching arithmetic* who have had little or no work in mathematics beyond algebra or a general mathematics course in the ninth grade.

Many elementary school teachers have had no further study of arithmetic itself after the eighth grade. They avoided mathematics because they were not too good in arithmetic. They never came to understand mathematics as quantitative thinking or science as a way of thinking and a tool to finding answers. In their schooling arithmetic was to them a memorization, follow-the-directions-and-see-how-you-come-out exercise. *There are elementary school teachers who had little or no science study in high school* or beyond. Such teachers can hardly be expected to instill in a large portion of their pupils an interest in, or an understanding of, these subjects. Their teaching will remain on the level of mechanical manipulation of figures in prescribed ways in order to come out with answers set forth in the back of the book, or of repeating facts about the birds and the bees and the wind and the weather that are set forth in the book, but they always live in fear that questions will be asked for which answers are not set forth in the teacher's manual.

Colleges preparing elementary teachers have made great strides of late years in changing their curricula to remedy this deficiency. The study of mathematics in college which will stress the development of mathematical concepts, understanding of the *development of number systems,* and *provide sufficient practice in use of mathematical* processes to develop reasonable skill and confidence is increasingly being required of all who would teach in the elementary grades. Likewise college level study in both biological and physical science is increasingly a requirement in preparing for elementary teaching.

Cities, such as Detroit, that for years have employed college graduates as teachers in the elementary schools have this problem in smaller degree than many places, but even in Detroit we need to examine our situation to see how extensively we are relying for the early training of pupils in arithmetic and science on persons insecure in their preparation or negative in their attitude toward the subjects.

A second condition is that of *closing doors to further advance in mathematics and science study for able pupils by action of teachers or by curriculum organization.*

A scientist must have his interest aroused early enough in life to prepare over a period of years. Thus arithmetic and mathematics and science work have been organized in sequential steps or courses. The potential scientist thus is expected to be interested in and to complete successfully each sequential step. His interest must withstand the competition of other interests, for if he has the capacity to be a good scientist he probably has ability to be good in other fields and he has a strong curiosity to find out about things. Thus science or mathematics interest must be sustained over a long period during which *it must be disciplined by sustained tasks that require concen*trated and at times tedious work. That, however, is true of developing a high degree of proficiency in any area. The immediate and long-range rewards—i.e., commendation and encouragement as progress is made, mixed with the right proportion of pressure to keep practicing when the going gets rough—holds for building high compe-

for many years) is the highest in the nation's history The *per cent* of high school pupils enrolled in science and mathematics also increased slightly. This is the first increase in percentage since 1910.

Here are some figures. Whereas in 1954 only 77 per cent of high schools offered courses in chemistry or physics to twelfth-grade pupils, in 1956 there were 82 per cent that did. Whereas in 1954 only 78 per cent of high schools offered plane geometry to tenth-grade pupils, the number now is 81 per cent

In 1952 there were 24.6 per cent of high school pupils taking algebra. It had increased to 28.7 per cent in 1956. This 28.7 per cent represents more than two million students, against slightly more than half a million in 1910 when the per cent of high school pupils taking algebra was 56.9 per cent

The percentage of pupils taking biology rose between 1954 and 1956 from 72 6 per cent to 75 per cent, taking chemistry from 31 9 per cent to 34 6 per cent, taking physics from 23.5 per cent to 24.3 per cent, taking plane geometry from 37 4 per cent to 41.6 per cent, and taking intermediate algebra from 28 5 per cent to 32 2 per cent.

One may regret that the percentage is no higher, but to have that much gain in two years' time in the percentage of pupils enrolled in science and mathematics when total pupil enrollment has gained appreciably each year, and to have the gain consistent for the several courses mentioned, is notable and heartening. And remember, this is in the face of a shortage of science teachers and science facilities in many places.

I call this to your attention, too, in the light of much publicized figures which point out that between one-fifth and one quarter of high schools do not offer physics or chemistry. Let us keep in mind that only about five per cent of the nation's high school pupils are enrolled in this 23 per cent of the high schools, probably one hundred or fewer pupils per school. This is because there are still about one-half of the high schools which enroll less than 200 pupils But here, again, we can note progress, for school district reorganization has reduced the number of school districts in the nation from 117,000 to around 50,000 school districts in less than twenty years' time.

And if we turn to the colleges we find that freshmen engineering enrollment has for the fourth consecutive year increased, and the ratio of increase is higher than that of college freshmen generally

When I turn to the situation in Detroit the picture of science and mathematics in the schools may be painted dark, gray, or white, depending upon one's point of view. In high school student enrollment the percentage of tenth graders enrolled in biology is 85 per cent against the national average of 72 per cent. In chemistry the percentage of eleventh graders is 34 per cent against a 32 per cent national figure. In twelfth grade physics the 24 per cent of Detroit pupils is the same as that for the nation. During the past three years Detroit high schools have graduated a few more than 9,300 pupils. All of them had at least one year of science, 42 per cent had two or more years; and 12 pet cent had three or more years.

Pupils in nearly all of the elementary schools have science instruction from a special science instructor. Pupils in junior high schools have science in each year and arithmetic is provided each year up to high school. Pupils who graduate from high school must complete at least one year of science and one year of mathematics. Additional science and mathematics offerings are available, but not required in all curricula.

The focus in arithmetic in Detroit schools during the past several years has been on developing mathematical concepts in addition to mastery of the skills Understanding relationships, and of how our arithmetic system is developed on the base of ten are considered important objectives as well as learning the multiplication tables. Last year new textbooks were selected for arithmetic and for algebra.

Detroit has for many years encouraged science clubs in its secondary schools to provide opportunities for those with special science interests and abilities to have freedom yet guidance in self-initiated activities. This year the schools are deeply involved in

Courses in any subject *field—properly taught—can* challenge and *require effort* and *application* by the learner. Those of ability and interest should be expected to do those things which require effort and to do them in ways that will exercise their abilities. *If progress is evident to them* and *the significance* of their activity and concentrated effort is clear to them, then continued growth and interest can be anticipated.

But let us not assume that all pupils will exert their full ability in all of their activities nor should they. You do not—or should not—eat as much as you could every meal. You do not walk or run to your full capability whenever you have a chance. You do not read every item in the paper as carefully as you might. No—you try to balance your diet to fit your needs and your tastes. You walk or run fast when you have to catch a train, but try to avoid that generally. You choose the items that you will read carefully depending on your interests, and on the time available from other things that you cannot control. Choice of *soft* versus *hard* courses is not peculiar to youth. You and I, given a choice, usually take the one that is the most attractive in terms of what we want—money, leisure, prestige, field of activity, location, future opportunity, security. We usually do not take the rough road if we can get there as quickly or at least on time by use of a more comfortable one. So must we expect that pupils will and should use their abilities in accordance with the significance they see in extending themselves to do high quality work.

Science and mathematics for those who would become tops in their field are probably no more rigorous than music and art and philosophy and law and medicine and the writing of prose or of poetry for those who are the high ranking scholars and performers in their fields. It is perhaps easier to detect those whose ability to perform is mediocre in science and mathematics than with the arts or social sciences, and thus to apply the right or wrong, pass or fail, procedure. But we need to be careful about applying the idea that science and mathematics are *harder*, and thus screen out potential scientists by fear that they might not be able to succeed. We need to be careful lest we eliminate able young people from science or math courses by applying more rigorous tests *or doing less to challenge their interest than is true in other fields*.

The G.I. program, especially, and other experiences, have demonstrated that some *able* persons may not have been interested or challenged by high school or college work. In the service or in working they developed a *new interest* or a new purpose which caused them upon return to school, college, or graduate school to devote great energy and full ability to mastery of problems and processes they had earlier avoided or done in cursory fashion.

The choice for them was not whether it was *soft* or *hard* but whether it was *significant to their purposes* and what they thought was important.

The fourth condition I shall mention is *restricting science opportunities to pupils because facilities are limited.*

Shortage of laboratory space is even now a factor of importance for many schools and colleges who have students able and willing to go ahead with science study. Lack of equipment to deal with nuclear science and electronics plagues teachers who themselves are equipped to work with students in these fields. If there were available more science teachers, and if a larger proportion of students continue to enroll in science, we have the problem of seeing that they are not frustrated by shortage of space and equipment for engaging in scientific study.

I have not here emphasized the greatest lack which restricts science opportunities, lack of sufficient well qualified science and mathematics teachers in elementary schools, high schools, and colleges. That is so fully recognized, I hope, that I shall but underline it here.

Now let me turn to efforts which have been underway by educators and citizens these past several years and indicate that progress *is* being made.

First let us look at the national scene. This fall the *number* of high school pupils enrolled *in science and mathematics courses (which has increased steadily year by year*

college. Electives are to permit a pupil to pursue his special interest and ability beyond the usual high school level.

9B	9A
†World History 1 (accelerated)	Composition 1
†Algebra 1-2 (accelerated)	Biology 1
†French 1 ‡ (accelerated) or Latin 1	Geometry 1 ‡
Health 1	Foreign Language (continued)
	Health 2

†Choice of 2.

‡ Indicates more than one term's work, but less than two.

10B	10A
Composition 2	American Literature 1
French 3-4 completed or Latin 3	Second Foreign Language or Latin
Geometry (Plane & Solid) completed	Advanced Algebra 1-2
Biology 2	Chemistry 1
Health 3	Elective

11B	11A
Composition 3	English Literature 1
Trigonometry or Elective	Analytical Geometry or Elective
American History 1	American History 2
Chemistry 2	Advanced Science
Foreign Language or Elective	Foreign Language or Elective

12B	12A
World or Modern Literature	Composition 4
Civics	Economics
Advanced Mathematics or Science	Advanced Mathematics or Science
Elective	Elective
Elective	Elective

ELECTIVES:

Art, Art Appreciation, Music, Music Appreciation, Public Speaking, Radio Speech, Dramatics, Qualitative Analysis, Quantitative Analysis, Organic Chemistry, Metallurgy, Bacteriology, Physiology and Anatomy, Electronics, Television, Radio, Sociology, Creative Writing, Hydraulics and Automation, Latin America, etc.

Pupils are regularly enrolled members of the high school, the same as pupils in the other programs offered by the school. They are not kept separated in any way except as they are in the accelerated classes. In extracurricular activities, they participate as do other students. §

Perhaps I have dwelt too long on what is underway in Detroit, and yet it seems to me that conscious as all of us must be today of our shortcomings in science education we need to point to specifics which show some of the steps that are being taken

§ The principal of Cass High School, Joseph G. Wolber, reported to the Wayne County Committee on Gifted Children that in algebra, where two semesters are taught in one, 57 per cent of the students are receiving an A or B grade. Dr. Wolber expects some 80 per cent of the students to receive an A or B grade in algebra at the end of the semester. Progress in mathematics has been so rapid that all the high school courses in the field are expected to be finished by grade 11B, which will allow the students to take a year and a half of college mathematics while still in high school. He remarked, "When we asked the C and D algebra students if they wanted to shift into a regular class where they would probably get an A, most of them refused."

the science fair program which culminates May 1-4 [1958] in the Metropolitan Fair at the State Fair grounds

The influence of a nuclear biology institute this past summer on bringing latest developments in this field to about fifteen Detroit high school teachers and providing them with apparatus and materials for carrying on instruction in their schools pointedly demonstrated the need for similar type opportunities for many more science teachers

There are three more activities in progress which deserve some comment as indicating steps underway to improve the education program, including science education.

The first is the city wide study of Detroit school needs inaugurated about a year ago. This two-year study, by a committee broadly representative of the lay citizens and educators on a city wide basis and by eight separate similar regional committees, is involving more than three hundred persons.

"What are Detroit school needs in the decade ahead?" is the question they are studying.

What changes in the science and mathematics program are indicated as one phase of that study.

I note this especially because in a recent message of the President the need for citizens to study their schools toward this end was one recommendation.

A second activity, provided for in the school budget this year, was the extension to the fields of science of a program well established in music and art. It is a program of classes on Saturdays for grade school pupils of special abilities and interests in the field. Preliminary planning during the first semester will permit the initiation of these science classes beginning with the second semester.

The third activity is a brief report on an experimental high school program initiated at Cass High School this fall that will challenge the boy or girl who has been blessed with a rare degree of intelligence, a keen desire to learn, and a willingness to work. The program will be accelerated, not in the sense that the stay in high school will be shortened, but rather that time and space will be found for enrichment through the study of advanced science and mathematics, and elective subjects which might be imposed upon the normal load program, and will include specialized subjects not ordinarily taught in high school

The criteria used for the selection procedure were as follows:

(a) Top eight per cent on the General Intelligence Test.
(b) Top four per cent on the composite score of the Iowa Multi-Level Tests.
(c) Superior grades in school subjects.
(d) Recommendation of classroom teacher
(e) Application by parent and prospective pupil for enrollment in this program

The Psychological Clinic and the Instructional Research Departments assisted in the screening of candidates for intelligence and general academic achievement. The program is designated as the science and arts curriculum. It is somewhat oversimplified, but reasonably descriptive to state that pupils in this program will, during four years as regular members of Cass High School, do five years of work. Their science and mathematics work during the fourth year, for example, will include analytical geometry and calculus 2 and a third year of laboratory science.

There are 202 presently enrolled. At the end of the first card marking two pupils were below passing in Latin 1. There were no other failures. One hundred thirteen made the school honor roll.

It is recognized that initial plans for the program will need to be modified in light of experience, and whether or not the program should be extended to other schools depends on experience with this group We believe it is a significant start on providing more adequately for those of high ability.

The outline of the curriculum by terms now seems to shape up as given below. It will be noted that most of the work is a required program preparatory for almost any

to reduce these shortcomings Ahead we expect to take steps for continued curriculum revision, for organized experimentation to try to provide for more continuity of pupils with the same arithmetic teacher and the same science teacher, to provide more science facilities and more up-to-date equipment, to have comprehensive testing in science and in mathematics for better placement of pupils in science and mathematics courses, and to provide more opportunities for science teachers to do systematic study on new developments in their field. These and other activities are certain to keep the superintendent in Detroit actively trying to keep up with the ideas and the needs of the school staff.

By the foregoing perhaps I have made clear several points. (1) that if science education is to produce scientists in the numbers and of the quality we need the problem is more than one of requiring that more students sit more hours in courses labelled science and mathematics, (2) that teachers, school administrators, boards of education, from elementary grades through advanced graduate courses all have important parts in the making of scientists and need to examine present practices to see the extent to which they may be frustrating as well as producing scientists; (3) that much progress is being made to improve and increase science education by school systems, including Detroit; (4) that the necessary improvement of science education is something that must receive attention, work, and added support for decades—not just months and years—and that it involves in addition to the best efforts of educators, votes of school boards, legislatures, the Congress, and citizens at the polls

And, as we assess the current and long range strength of this nation and consider steps to improve the preparation of its citizens we cannot afford to overlook or to discount an intangible element which is as important as, or of greater importance than, what I have discussed. It is that we must relate science education to the beliefs held by persons which spur their efforts, sustain their hopes, and maintain their cohesive action regardless of hardship. Scientists and engineers who lack appreciation for spiritual values, a citizenry lacking in beliefs beyond mere survival, emissaries to other nations who are primarily concerned with what they can secure from them rather than what they can do to make living more significant and meaningful for them, can undermine and perhaps wreck the military and technological superiority we may have or develop It may even be possible that the preparation of missionaries, of philosophers, of teachers, and of health specialists dedicated to improving the living of people in other nations should have equal or higher priority than the preparation of scientists and technicians.

vide tours for junior and senior high school students to local industries in order to stimulate more interest in basic courses in mathematics and science. The Committee's purpose in this program was stated by one of the industry members as follows, "The mission in this case is quite different from the usual trips taken through plants in which there is an effort to show the whole plant or to sell the particular industry to the visitor. In this instance, the mission is rather to create in the students a real interest in science." In this pilot project, 42 ninth grade boys were identified by algebra teachers as being capable students who could carry the story of what they saw back to their classmates. Science teachers of eighth graders did the same

One of the groups of teachers, employed by the Allison Division of General Motors during the summer, was assigned the task of making a detailed study of the important things for youngsters to see They also identified the Allison people who could talk to and inspire these youngsters The whole day's program and itinerary were planned in advance The same was done by personnel of the Eli Lilly Pharmaceutical Company, the other industry participating in the pilot project The project was carried out on November 8, 1956.

Outcomes: The Committee decided that it must try to evaluate as many of its projects as possible. Consequently, reactions were solicited from pupils and teachers which might indicate the degree to which this kind of program achieved the desired outcomes The following are typical responses received

"I most enjoyed my visit with Frank Blair, Jr (Allison) He talked to our group on the computer while he was testing a torque converter It was the only application of math to engineering I saw. I would have enjoyed seeing more engineers at work and less torque and transmission testing."

"I have been thinking of entering a field of science for some time, but I have not yet decided what field I should enter The trip to the Eli Lilly Company gave me many new ideas and has helped me to better understand and decide which field of science to enter."

"Since David is interested in electricity, he particularly enjoyed seeing the electrical testing equipment and the electronic 'brain' Seeing the planes at Plant 10, talking with the workers, and visiting the Powerama were all highlights of the day."

An assistant principal wrote, "I personally feel the science tour was of great benefit to Dick It provided him with more confidence, both in the classroom and school generally. The tour has resulted in more attention being focused on science from the other pupils. Many pupils have asked about the opportunities of taking a similar tour, and seem to feel that going as an individual is more of an honor than going in a group "

The Committee believes this to be a sufficiently valuable kind of experience that it should be increased fivefold in February or March of 1958, and should include both boys and girls.

PROPOSAL 5: That Business Education Day plans be modified this fall in such a way that science and mathematics teachers can be grouped and invited to plants where specially designed programs can be prepared for them. The Committee's purpose was to increase the effectiveness of this program which was originally designed to raise the awareness and appreciation of the relationship of education to the community's business and industrial life Four industrial firms participated in the modified program which was carried out on November 16, 1956, through the co-operation of the Chamber of Commerce and local schools.

Outcomes: Inquiries were sent to all teachers participating in the modified B E Day program as follows: "Members of the Industry-Schools Committee on Science and Mathematics Education are interested in evaluating the programs offered by the several industries to science and mathematics teachers. Would you please give us your help by writing your criticism of program this year and suggestions for program next year."

The following are typical of the responses received:

sponsorship is provided by the Indianapolis Board of School Commissioners and the Indianapolis Chamber of Commerce.

At its organization meeting on June 19, 1956, the Committee was asked by its sponsoring organizations to consider initially the following problems or questions:

1 How can more young people be stimulated (or required) to take basic courses in mathematics and science to prepare them for college training in technical and scientific fields? What devices or methods might be put to use?

2 Are there enough able teachers in mathematics and science?

a Is there need for stimulating more bright young people now in high school to make teaching in these fields their career?

b Is there need for refresher courses for present teachers in these fields?

c Is there need for more laboratory equipment in the schools?

d. Are the curricula in these fields adequate to our needs?

3. Is there too much interference from having too many course offerings which are not so fundamental?

4 What contribution could be made on any of the above subjects by the part time participation of men in these fields now in the employ of industry?

Statistics were studied regarding enrollments in high school mathematics and science courses, the time given to science instruction in the junior high schools, and the training of science and mathematics teachers. Articles in professional journals and papers were reviewed. Attention of the Committee began to focus on selected hypotheses, including the following:

1. *Inspiration and guidance of enthusiastic teachers will do more to interest pupils in science and mathematics than will anything else. Upgrading science courses will in*crease enrollments.

2. Improving instruction in science and mathematics is an important long range aim. But there must be measures that can be taken immediately to interest youngsters *in the opportunities in vocations related to science. Pupil visits to laboratories* of local industrial scientists might help.

3. Science instruction in many elementary and junior high schools consists largely of *reading about science*. More laboratories should be provided.

4 *Science and scientists will flourish best where all people* are more literate in science and more appreciative of it.

During the seventeen months of the Committee's existence, its work has included eleven specific undertakings. The following thumbnail descriptions include proposals made and outcomes to the present time:

PROPOSAL 1. That the Committee on Science and Mathematics Education make formal requests, through the superintendents of the various public school systems of Marion County, that sufficient funds be budgeted for the year 1956-1957 to supply equipment for an adequate science program in each junior high school, and that a suggested list of equipment be submitted.

Outcomes: This recommendation was sent to all school superintendents of Indianapolis and Marion County. Although the Indianapolis Board of School Commissioners was already well into its budget preparation in July, it appropriated $60,000 for equipment and supplies for six junior high schools. This was fifteen times the amount appropriated in any one preceding year. At the same time a Consultant in Mathematics and Science was named to head up an intensive inservice education program in the use of this equipment. My associate, Dr. Newton G. Sprague, will include the discussion of this program in his presentation which follows. Other school districts of the metropolitan area informed the Committee that they were taking cognizance of the recommendation by strengthening their science programs.

PROPOSAL 2: That a pilot program, sponsored by local industries and Marion County schools and coordinated by the Committee, be carried out in the Fall to pro-

to teachers. Twenty companies indicated the availability of 78 jobs. Teachers were also polled to determine their interest in such opportunities. One hundred teachers responded. Names of teachers were made available to industries, and information as to job opportunities was provided to teachers. An appraisal is being made.

PROPOSAL 8: That a request be made to a local foundation for money to assist science and mathematics teachers in continuing their study in these subjects.

Outcomes: On September 13, 1957, the Indianapolis Foundation granted $10,000 to the Industry Schools Committee for use during calendar year 1958. The grant is renewable for two additional years.

On their own initiative, the Eli Lilly Foundation, the Indianapolis Foundation, and the Indianapolis Junior League have given additional funds amounting to several thousand dollars to the Indianapolis Public Schools for special education of teachers of gifted children.

PROPOSAL 9: That all Boards of Education be urged to budget funds to pay expenses of high school mathematics and science teachers attending professional conferences.

Outcomes: The Indianapolis Board budgeted, for 1957-1958, $3,600 to send mathematics and biological and physical science teachers from the eight high schools to such conferences.

That amounts to $450 for each high school, which is not a tremendous sum, but it will send several representatives from our departments of mathematics, natural science, and physical science to meetings this year.

PROPOSAL 10. That, since quality of teaching greatly affects pupil interests, all school boards be urged to improve financial incentives to attract more capable people into science and mathematics teaching.

PROPOSAL 11: That criteria of adequate high school laboratories and equipment be developed and furnished school authorities for appraising existing facilities and planning new ones.

The Industry Schools Committee on Science and Mathematics Education held its regular monthly meeting on November 20, 1957. In the light of the current situation, including the teacher manpower situation, which we believe cannot be changed overnight through education alone, the members concluded that measures must be taken to determine our existing local scientific manpower resources, and to take action which seems necessary to assure the most efficient use of this manpower by the entire community, school, industry, and military organizations particularly.

After extensive discussion, the following proposals were approved: that the Boards of Education of Indianapolis and Marion County should be urged to make thorough studies of the competency of their teachers in grades one through twelve, to determine the science and mathematics teaching potentials of their entire staffs; and further, that they should be urged to make whatever adjustments seem best to assure the most effective utilization of this teacher potential, and further, that they should provide training free from cost to teachers in science and mathematics subjects at high school difficulty levels for elementary teachers as well as at college and university levels for others, this work to supplement the training of the undertrained and to retrain those originally educated in other fields. Finally, that the Boards should be urged to grant compensation to these teachers for their time spent in such course work. I would like to comment that this only proposes an application to education of what industry has been doing right along and what has been proposed and apparently will be carried out at the national level and the international level.

The second proposal made yesterday is that the industrial concerns represented on the Committee proceed with a study of their own personnel to identify potential teachers who might be made available for teaching assignments. A report of suggested means of assistance by industry with the teacher shortage should be made at the next meeting.

The third proposal was that a study be undertaken by this Committee of the retired military personnel in the area who might be competent in the fields of science and mathematics and interested in teaching in secondary school or college with or without additional training. These proposals are not all original; the importance is that we are adopting them for Indianapolis.

The fourth proposal was that the Committee and its sponsoring organization draft a resolution to be addressed to our United States Congressmen and Senators and to the appropriate presidential aide to the effect that the National Selective Service Boards should exempt from military service all teachers licensed to teach and actively engaged in teaching science and mathematics at the secondary school and college levels, and further, that any such teacher now in the Armed Services should be released on joint requests of the individual and of the local boards of education or college board of trustees for such time as the teacher remains in satisfactory teaching service. Finally, that any youth successfully engaged in college preparation for teaching science and mathematics at the secondary school or college level be exempt from military service during the training period and for as long thereafter as he shall be actively and successfully engaged in teaching mathematics and/or science at the junior or senior high school level or at the college level.

The Committee also proposed that local boards of education be urged to institute a systematic procedure for appraising the general educational development of all their pupils to identify those with scientific aptitudes, and further, that they develop more effective means for counselling pupils and their parents regarding the development and use of these potentialities.

I wish to close with the thought that the challenge of identifying potential scientific talent among our children and youth, and of inspiring the needed numbers of these young people to prepare themselves for science-related vocations, must be met in local communities across the nation. It is here that children live, grow, and develop their hopes and aspirations. It is here that they receive their early experiences, in and out of school, through which all later learning is attained. It is from Hometown, U.S.A., that the nation has always drawn its strength. It is from Hometown, U.S.A., that it will draw its strength in the future.

UPGRADING STAFF AND EQUIPMENT

DR. NEWTON G. SPRAGUE

Consultant in Science and Mathematics
Indianapolis Public Schools

The Indianapolis Board of School Commissioners appropriated approximately sixty thousand dollars for science equipment and supplies during the 1956-1957 school year, for the 74 junior high schools (seventh and eighth grades). Money is one thing and converting it into usable supplies is another.

In the past several teacher committees had developed supply lists for the various units given in the junior high school science course of study. However, since each school was limited, at that time, to an expenditure of $25.00 per semester, the lists were not very extensive, but they were the starting point.

Other sources of information for teacher equipment and supply needs were Curriculum Bulletin No. 20, *Science—A Guide For Teachers—Junior High School*, and *Curriculum Bulletin No. 20 Supplement, Related Science Activities—Junior High School*. These are two publications which were developed during a period of time between 1953-1955 by the junior high school science teachers of Indianapolis. Many of the activities given in the bulletins required specific equipment and materials.

Blueprints for community action **3**

The Oklahoma science education story*

FROM ARROWS TO ATOMS

DR. JAMES G. HARLOW
Executive Vice President
The Frontiers of Science Foundation of Oklahoma, Inc.
Professor and Dean
College of Education, University of Oklahoma

The aims of the Frontiers of Science Foundation are substantially broader than those which usually govern improvement of education in science and mathematics. Actually the Foundation was set up to move Oklahoma's population through a change in outlook which would normally take one or two generations. we are trying to make the change in something like five years. We call this change entry into the new frontiers," following Vannevar Bush's caption of his famous report, Science—the Endless Frontier." Our concern in Oklahoma is the development of a twentieth century social order in which the central activity is exploration of the new scientific and technological frontiers.

Our programs are organized under three categories. public information, educational programs, and installations programs The public information programs are aimed at the development of a public attitude to permit the kinds of change in educational, economic, and social policies which are necessary for life in the last half of the twentieth century. The educational programs are designed to stimulate improvement in science and mathematics education at all levels in the State's educational system from grade one through the graduate schools of the universities The installations programs are to stimulate the development of science based industry in Oklahoma and to attract to Oklahoma the kinds of industries which are characteristic of the new frontiers.

In our public information programs, we maintain contacts with all the mass media, principally the newspapers, and some work with radio and television But the spectacular things are attempts to demonstrate directly what is meant by the new frontiers. The Geneva Atoms for Peace Exhibit was presented in the spring of 1956 It was open for eight days, and attracted some 550,000 visitors. Last summer we held a one-day symposium entitled "Oklahoma's New Frontiers of Science: Industry and Education" The symposium was addressed by ten of the world's ablest administrators in research and education, seven from the United States and three from Europe This symposium produced crowds never under 1,800 people, and the total attendance was nearly 5 000 people.

A semicentennial exposition in Oklahoma this summer attracted roughly a million and a quarter people. At that exposition a 23,000 square foot display building was given entirely to the interpretation of research as a process, with displays from the Bell

* Addresses presented at the Eighth Institute of the Thomas Alva Edison Foundation, November 1957, and published by the Foundation in pamphlet form under this title.

course for them to take, certain suggestions to change this were made by a committee composed of the assistant superintendent in charge of curriculum and supervision, the consultant in science and mathematics, and two high school principals

On February 26, 1957, the general superintendent, Dr. H. L. Shibler, presented, and the Indianapolis Board of School Commissioners approved, the following resolution: " . . Beginning in September 1957 every Indianapolis high school shall offer a science course to every 9B pupil, who, in the judgment of the principal, has the ability and the maturity to profit from the course. No later than September 1958, a new course in physical science be developed for all 9B pupils wishing to elect it, within the necessary restrictions pertaining to class size. For graduation from Indianapolis high schools, beginning no later than with the graduating class of 1961, there be required a minimum of one year of physical science and one year of biological science, one of which must meet the state requirement of one unit in a laboratory science." This ruling will necessitate the construction of more science laboratories and the hiring of more good qualified science teachers

May I refer now to the increase in our high school science enrollments. In the fall semester 1955, the science enrollment was 4,479 or 27.4 per cent of the total high school enrollment of 16 362 At a similar date in 1956, the science enrollment was 5,575 or 34 7 per cent of the total high school enrollment of 16,075. This fall the science enrollment was 6 824 or 41 7 per cent of the total high school enrollment of 16,346 This shows a gain of 7 per cent for each of the past two years Part of this is due to the School Board ruling of February 26, 1957. However, we are certain that a part is also due to the new emphasis placed on science throughout the country and in our junior high schools during the past school year

At this point, it might be interesting to look at our changes in high school science personnel during the past year Two teachers were lost to industry, three to universities, one to a private school and one to his own business On the brighter side, our high schools gained four from the junior high, two from county schools, two from the military, and five from other sources The industries of Indianapolis are to be complimented on their summer employment of science and mathematics teachers. This is a very important way of helping the good teacher remain in the classroom nine months out of the year.

With the science program gaining momentum, attention has been turned to an other important area, Modern Mathematics and Its Implications for the Secondary Curriculum So far this fall we have had Dr Sawyer as a speaker. In December we will have another, Dr Bing A second part will be a series of five lectures, January through May. The meetings will be held after school, 3 45 P.M. 5 00 P.M. Seventy five teachers have already indicated a willingness to pay an enrollment fee of $7.50 for the series This interest I am sure is due, in part, to "Seminars in Sciences" which were paid for by industry last spring.

An interesting experimental program is now in progress at Arsenal Technical High School to appraise the possibilities for conserving more of the lesser-talented in mathematics for technical level jobs The experiment is to determine the motivational value of the machine calculator in teaching mathematics As we look to the future, it is planned that greater emphasis will be placed on student participation in Science Fairs this year. Greater use will be made of experimental science programs on television and radio Co operation will continue and increase between the junior high school science teachers and the junior high industrial arts teachers who have helped supplement our science program this past year with units on electrical symbols, wiring diagrams, radio theory, wire splicing, etc

We feel in Indianapolis that our program will continue to expand We hope that it will help correct the shortage in science and technical personnel which our country faces today If we can be of any assistance in the development of a similar program in your "home town," feel free to call on our resources.

Publishing Company, personally financed the work leading ten or fifteen years ago to the establishment of the first elementary science curriculum in Oklahoma. The University of Oklahoma set up a high school science service ten years ago to stimulate interest in secondary school science on a state-wide basis, with full collaboration among the science departments and the college of education.

All these activities came together in the planning for Oklahoma's semicentennial celebration held this year. When the Oklahoma City Chamber of Commerce started to plan this celebration, it cast about for an exposition theme, and a real triggering operation was the result. Oklahoma is a young state—a first-generation state. Many of the men who literally built it are still alive and active. The new frontiers of science provided an exposition theme which intrigued these builders. The result of their casting about was their discovery of the grave national problems in science and technology. In the excitement of its discovery, the exposition committee set up the Frontiers of Science Foundation, promptly promoted four hundred thousand dollars to support it over a five-year period, set the Foundation off on its course, and turned back to its business of planning the exposition.

The Foundation has been in operation since October 1, 1955 It has a membership of roughly 150 individuals. Its money is coming from subscriptions by individuals and by business firms. It has involved the leadership groups in Oklahoma very intimately. The present officers include two major oil company presidents, and a major publisher; the Executive Committee includes two other newspaper publishers, two bank presidents, the presidents of our utilities companies, the presidents of our major universities, the chancellor of our State Board of Regents for Higher Education, the State Superintendent of Schools, and the superintendents of our two largest city school systems. Professional groups are represented through the president of the medical association, for example, representatives from the society of engineers, and so on. The Foundation is an organization which started right at one of the power centers of Oklahoma.

From its inception, it has involved the principal decision making agencies in the State, and this is the reason why we are able to move rapidly on programs in education and in the development of effective public attitudes We are more nearly a voluntary organization than a foundation in the usual sense.

I am new enough with the Foundation that I am still wide-eyed about the things they are doing and plan to do. The Frontiers of Science Foundation is not concerned alone with the improvement of education in science and mathematics. Its dream is nothing less than the creation of a distinctive scientific-technical innovative democracy. It is working in an area of high national concern, and attempting to make a major contribution.

It seems to me that the reason why we are getting results in Oklahoma is that the task of improvement of science education is not regarded as simply the task of the schools. These problems are regarded as involving everyone in the State; the attitudes of people who vote for school board members are important factors in the development of education programs which more nearly fit the times in which we live. Instead of approaching our problems with the idea of restricting responsibility to educators, our school staffs are looking outward, they welcome into their long range planning particularly, and to some degree into their short range planning, representatives of other sections of the society.

In Oklahoma, we are trying to restate our educational problem. Instead of talking about hours in class or credits to be required, we talk explicitly about what we need in the way of a population informed with respect to science. Instead of requiring high school physics of everyone, as a recent Gallup poll reports most Americans favor, we should recast this and ask what is the rock bottom of competencies in physics for effective citizenship in the United States, today—and tomorrow. The reason we need to do more science in the schools is that there is more science outside the schools.

Telephone Laboratories, IBM Research, the Fansteel Metallurgical Corporation, and so on, and about a half dozen of the major governmental units, the Office of Naval Research, Institutes of Health, the Patent Office We also showed the best science films we could get There was a counselling center for young people, staffed with counsellors from secondary schools and colleges in Oklahoma Approximately 240,000 people visited the building, and the counselling center attracted about 2,400 young people.

We arrange speaking opportunities for scientists and administrators coming through Oklahoma On rather short notice, we have gathered groups of six to eight hundred business and educational people to hear leading scientists, engineers, and administrators in research and engineering.

Groups of our own people have been going at their own expense to visit major research installations all over the country When it was decided to undertake a frontiers of science activity, many of our leaders thought they should see what a frontier of science looked like One of the oil companies provided an airplane, and groups went to the Argonne Laboratory near Chicago, to Brookhaven, to the National Bureau of Standards, and other major research centers Groups have also visited the Massachusetts and California Institutes of Technology and the Ramo-Wooldridge Corporation The Tenth Investigatory Tour, held this fall, went to the Stanford Research Institute and the Stanford Industrial Park on the West Coast These tours have been among our most effective devices, because through them community leaders have become directly acquainted with problems of science and engineering, and with problems of education in these fields.

As education projects, we conducted one major talent discovery and curriculum assessment program through a state-wide testing program of which Mr. Spencer will speak. Oklahoma has just published a new mathematics curriculum for grades one through twelve, work for which was supported by grants from the Frontiers of Science Foundation We are distributing 24,000 copies of a special guidance folder, designed to interest young people in science careers at all levels, from secondary school graduation clear through to the Ph D. level In October we had a two-day conference in one of our major universities addressed to the stimulation of interest in community science fairs

We are maintaining an information service for all secondary school teachers in the State. Roughly once a month we mail a packet of materials to these people. These include speeches which may have particular relevance to our problems in Oklahoma, freshly available guidance materials, suggestions about curriculum, and reprints of stimulating articles.

In the installations activities, we have been assisting our major research institutions in the development of adequate investigative facilities in each place. Within the past year, the Atomic Energy Commission installed two small research reactors at the University of Oklahoma and at Oklahoma State University. The one at Oklahoma State is now in operation, and is the hub of a new program of training engineers in nuclear physics. We are currently seeking funds to establish a major numerical analysis center with a general purpose and research computer, either at the University of Oklahoma or Oklahoma State.

Two large modern plants have decided to locate in Oklahoma and have reported that their interests were sharpened by the activities of the Frontiers of Science Foundation These are a Western Electric plant, manufacturing the new crossbar relay equipment which is the central unit in the long distance dial networks, and the Fansteel Metallurgical Corporation's plant which will manufacture rare earth

How the Frontiers of Science Foundation came into being is quite interesting For a good many years, many Oklahoma people were interested in the improvement of education in science and mathematics The Oklahoma Academy of Science has had an active High School Relations Committee for more than twenty years. The Chairman of the Foundation's Board of Directors, E. K. Gaylord, President of the Oklahoma

decided to do it, in as short a period as six weeks, the professional educators asked the individual high schools to come into the program on a voluntary basis. In six weeks, more than four hundred high schools across the state, involving well over half the high school population of the state, did come into the program.

We tested over sixty thousand students in one day, in grades nine through twelve. The testing battery used is called the Iowa Tests of Educational Development. They are generalized achievement tests which are designed to measure not only what a student learns in school, but out of school also, in eight major fields of education.

I will not say these tests are infallible, because they certainly are anything but that. The way we look on them is, although they are anything but perfect, they are probably the least bad evaluative devices on a broad scale that are now available. A number of longitudinal studies made with them indicates that their value for predicting later college success is typically quite good. As a matter of fact, one outside study done with them indicated that scores on these tests made at the beginning of the ninth grade were slightly better predicters of later college achievement than all the school grades put together at the end of the twelfth grade. Combining school grades and test scores, however, are a better predicter than either one of these individually. The correlations with later college success are typically in the middle sixties.

In addition to the Iowa tests, one other experimental attitude questionnaire was used to attempt to reveal educational expectations, in order to cross-tabulate test scores with whether the students expected to go to college or not, and to find the critical cases on whom most of the work needed to be done. This work, by the way, was done by Dr. Samuel Stauffer, the Director of the Laboratory of Social Relations at Harvard, and in part subsidized by the Ford Foundation.

Briefly, the results of these tests indicated that Oklahoma was slightly below the national average in terms of educational development. Furthermore, at the high school level, they were not growing quite as fast educationally as were students of the high school level of the rest of the country. The thing that really excited and gratified me was that, instead of being defensive about these findings, the state teacher committees set to work immediately to find ways of improving the curriculum, both in the area of mathematics, and also in the field of English. Another finding that was exciting was that more than seven thousand students were found who rated in the top twenty per cent nationally in science and mathematics tests.

One other thing was done that later proved to be one of the most important motivating factors, although we did not think about it in this connection at the time. Mr. Dean McGee, who is the President of the Kerr-McGee Oil Industries, and Chairman of the Oklahoma Frontiers of Science Foundation, sent personalized letters to all of these seven thousand very bright kids. The result of that letter proved again that results that are possible through motivation are much larger than we usually think. It demonstrated again that many students literally do not know that they are bright, and neither they nor their parents realize the career consequences that can occur as a result of trained intellectual brilliance.

Generally, psychologists do not consider that it is good policy to communicate to students directly, or their parents, the results of intelligence tests per se. The reason given is that if a student is not bright, nothing can be done to improve it. As a matter of fact, that really is not so. The way we broke through this barrier is to be careful to call these tests that we use educational development tests, and to make the point that anyone can improve if he works harder, which he can.

It happens that embedded in this battery of nine different tests making up the Iowa Tests of Educational Development are all the elements we usually call intelligence tests. There is a distinction between what we call intelligence tests and what we call achievement tests, but even what we call the purest intelligence test can contain a lot of learning factors in it. I would like to see the term "intelligence tests" dropped in schools, because what has previously been a negative thing can be turned into a

A great outlay of money, at least in this case, was not the key to getting this program off the ground. The total amount contributed by businessmen at the beginning was four hundred thousand dollars for five years, or about eighty thousand dollars a year. This money was raised in a very short time which was impressive, but this is not a large amount as support for programs of this kind goes.

As far as the talent identification program was concerned, only five thousand dollars was contributed by the Frontiers of Science Foundation. Beyond that point, the schools did it for themselves. The point again was that the meld between the educational leaders and the business leaders and the enthusiasm that became infectious in the interaction between these two groups.

Still another aspect of this financial situation was that in getting the program going and getting the students later to go on to college, scholarships played almost no part. So often the first thing we think of and the first thing businessmen think of when we want to do something is to give some scholarships to see if we cannot get more of these bright kids to go to college. Oddly enough in Oklahoma there was no enthusiasm for this idea among the businessmen; in fact there was a distinct feeling among many of them that scholarships might be bad, that this would produce attitudes of something for nothing or that the world owes bright kids a living. Personally I think that this position is too strong. Nevertheless, it is most important to note that in our first follow-up study the following fall, of the four hundred students who were brightest in the twelfth grade in the spring, 316 of them did start to college that fall, and many of the other eighty-four still planned to go. Less than twenty per cent of these received scholarships or other substantial financial aid of any kind, and a great number of these students came from poor financial circumstances.

I suspect that as we go along we are going to find increasingly that motivation is much more important than we have previously thought, and that lack of money is often a verbal crutch for kids who do not want to go on to college or later want to drop out of college for other reasons. What we need to do is to find out, through intensive investigation, not just by questionnaires, much more about the assumptions on which these decisions are based.

We learned in Oklahoma that it is important when we enter these programs not to interpret the program too narrowly, not even to say that the program should only be for future mathematicians, scientists, and engineers. We did restrict the program in Oklahoma, and I now conclude that it was a mistake. Most bright students are very idealistic and highly malleable. I could tell you about other experiments we have run in other cities, where in a short time we have been able to increase the number who wanted to go into any given occupation in the field of the sciences by as much as fifty per cent. We are beginning to suspect that this sort of program is too narrowly conceived, and can produce later backlash. Furthermore, none of us who are in this field are omnipotent, and it is easy to make mistakes. I think a much better approach is to start out by attempting to enlarge the total brainpower pool, and provide good counselling once we have identified the bright students.

When we say the only important jobs to consider now are science and engineering, immediately we set up covert opposition, even if it does not become verbal, among people in other professions or other fields who also feel a shortage of brainpower. For instance, my own company needs many more good psychologists than we can get. A year ago I made a talk before a professional group on the need for scientists. Later I got a choleric letter from a lawyer who said that his law firm needed good young lawyers very badly, and he was not going to support any program in which the law schools did not have a chance. I might add that certainly there is an enormous need for more good teachers in any field.

Related also to this subject is that in the training programs for these bright kids, even when we do get them into science, we want to be very careful that their training programs are not interpreted too narrowly. We just finished a longitudinal, six

very positive and rewarding thing, when the student who receives a low score is encouraged to bring it up with hard work

One of the results of the tests was that the following fall there was an increase of around twenty-seven per cent in enrollment in science classes in schools that had participated in the program the previous spring. There had also been a great deal of publicity about the program, and there was an increase of nearly fourteen per cent in science and math class enrollments in the schools that had not participated. Again we think this was largely due to the resulting publicity, because there was relatively little guidance work yet being done in Oklahoma. This was achieved mainly by classroom teachers who buttonholed bright students when they came back to school in the fall, and said, "If you don't take the hard courses"—and they did not have to—"you are only going to be hurting yourself in the long run." This sort of argument makes sense to kids and it also makes sense to parents.

In terms of individual careers, I felt it was even more touching. There was one girl that came in the upper five per cent of all the students nationally on these tests, who had been in an orphanage for a number of years. She showed her aunt the letter that Dean McGee had written her. Within a month, her aunt and uncle adopted her. They could have done this any time in the previous ten years, but apparently the idea that they had a bright child in the family was such a stimulating thought that it produced this major change. Another example that appealed to me was a junior who was the star football player in one of the suburban schools near Oklahoma City, and football is not a subject that is entirely forgotten in the State of Oklahoma. It turned out that he was in the ninety-fourth percentile on the science and mathematics test. Up to that time, he had not been taking an academic course, and he had not planned to go to college. As a result of the test results and some good counselling afterwards, he decided that he was going to become an engineer. But he was told he would need *four* years of mathematics to do this. He had only had one year, and had already stopped taking math, and he only had two years or even a little less than that in school before he was going to college, if he was going to do it. He changed his whole course, taking intermediate algebra at school, and he also took trigonometry and solid geometry by television on his own. One semester later when we checked on him, his grades were averaging A minus and he was still a good football player.

I have only mentioned a few examples, but they are by no means unique. They are only illustrative of the major career changes and motivational changes that can be produced in young people if a talent identification and counselling and guidance program can be set up.

I would like to mention some of the major implications that seem to come out of this Oklahoma experiment, which are generalizable across the country. I realize that many of these points are quite controversial, and I am quite sure not everyone would agree with some of these points.

The first one is that if this sort of program is going to get off the ground in a community, in addition to strong support from educational leaders, absolutely vital is the major support of the thoughtful, big business leaders in the community. This impressed me very greatly in Oklahoma. This was not lip service support. This means inviting educational leaders into the homes and private clubs of the businessmen, where they got to know one another, and develop the kind of trust which I think has not been produced before. It is also essential that when businessmen get involved in this sort of thing, they give their support but not try to get down to the how-to-do level in working out programs of improving a science curriculum.

Another thing that I think had some relationship to the success of the Oklahoma program was that, at an early stage, outside recognition of the program was also received. The National Science Foundation came through within the first six months with a grant for $250,000 to set up a year-long institute at Oklahoma State University for the training of science and mathematics teachers.

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year follow-up study of students whom Science Research Associates had tested in the twelfth grade. We followed them all the way through college to find out who were the brightest ones, who did best during their four years of college. In the area of engineering, just as one example, we found that those who were going to be successful, whether they were C students, B students, or A students, had to be very good. They had to be in about the top four per cent in their science and math tests. But the tests about the engineering students that really discriminated between those who graduated as A students and those who graduated as C students were the scores that they had made on reading comprehension in the field of English literature.

It is quite evident that much more basic research in this field is needed on a longitudinal basis. The testing program in Oklahoma was done for grades nine through twelve. I am now convinced it should have gone down at least to the seventh grade and probably much further. There is a great need at this time for an evaluation and assessment through the entire continuum—starting maybe at the age of six months, through kindergarten, elementary school, high school, college, graduate school, and on into the distinguished research laboratories of our country—to find where are the places that, if we apply pressure, we can have the maximum impact in changing their careers, getting them more seriously motivated to want to go on with their study and work.

I cannot help but have the feeling, and I get it increasingly, that particularly those of us in the field of education need to be much more decisive than we have been in getting programs of this sort started. We need to act more and possibly to talk less. We need to set objectives and start out after them without too much second-guessing and self-doubt. I have seen so many programs that appeared to have great promise come to nothing because those who were running them were really motivated more by fear of making possibly wrong steps than they were by desire for action.

In the business world you see all the time the tradition of progress that exists there. In most businesses growth is taken as a matter of course. It has been said that the three per cent annual increase in labor productivity per year is the most important single statistic underlying our economy. I often feel that this tradition of progress is somewhat lacking in the field of education, although possibly not for any reasons for which we are responsible. Educators have been criticized so frequently that defensiveness has often resulted. We are too frequently in the position of having to prove that education has not deteriorated in the last generation, rather than taking a positive view that it is good now and we have lots of ways to make it get better.

Finally, it may just be possible that our timing now is righter than it has ever been before to make measurable progress in the future. I like Mr. Kettering's restatement of the second law of thermodynamics, that you can't push something that is moving faster than you are. I hope that this is not the situation these days, particularly between the United States and Russia.

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